

**FINAL REPORT-STUDY OF
THE APPLICATION OF ADVANCED TECHNOLOGIES
TO LONG RANGE TRANSPORT AIRCRAFT**

Volume II — Advanced Technology Program Recommendations

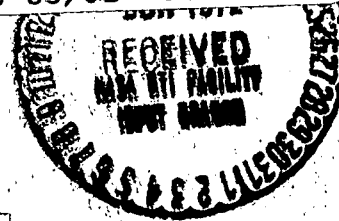
MAY 1972

(NASA-CR-112093) STUDY OF THE APPLICATION
OF ADVANCED TECHNOLOGIES TO LONG RANGE
TRANSPORT AIRCRAFT. VOLUME 2: ADVANCED
TECHNOLOGY PROGRAM (Boeing Co., Seattle,
Wash.) May 1972 245 p

N72-26007

Unclas

CSSL 01B G3/02 31365



Reproduced by
**NATIONAL TECHNICAL
INFORMATION SERVICE**
U.S. Department of Commerce
Springfield VA 22151

Prepared under Contract No. NAS1 10703 by
THE BOEING COMPANY
Seattle, Washington 98124

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

**FINAL REPORT-STUDY OF
THE APPLICATION OF ADVANCED TECHNOLOGIES
TO LONG RANGE TRANSPORT AIRCRAFT**

Volume II — Advanced Technology Program Recommendations
MAY 1972

**Details of illustrations in
this document may be better
studied on microfiche**

Prepared under Contract No. NAS1-10703 by
THE BOEING COMPANY
Seattle, Washington 98124

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

	Page
ABSTRACT	1
SUMMARY	3
INTRODUCTION	5
Study Objectives and Schedule	5
Background and Related Activities	7
General Study Approach	14
Basis for Recommended Program	18
SYMBOLS AND ABBREVIATIONS	19
INTEGRATED PROGRAM	23
Program Scope	23
Significant Item Payoff Potential	23
State of Readiness	31
Total Program Cost and Schedule	31
Program Assessment	38
Program Priorities	40
RECOMMENDED ACTIONS	43
Introduction	43
Design Integration	44
R&D Program Integration	44
Low Noise/Congestion Configuration	48
Maintenance and Delay Reduction	50
Aerodynamic Configuration	53
Advanced Airfoils	56
High Critical Mach Cowl	62
Subsonic/Transonic Area Ruling	65
Analytical Methods—Improved Design and Analysis Tools	67
Novel Design Concepts	69
“Interference-Free” Transonic Test Section	78
Flight Wind Tunnel Correlation	87
Roughness and Excrescence Drag	89
Sonic Boom During Cruise Slightly Below Mach 1.0	92
Structures and Materials	94
Advanced Filamentary Composite Structure	97
Bonded Aluminum Structure	110
Improved Corrosion Protection	122
Titanium Structure	126
Improved Steel Structure	129
Integrated Active Control System	129
Structural Design Methodology Development	138
Power Systems	142
Propulsion System Flight Demonstration	148
Engine Cycle Impact	150
Turbomachinery Noise	150

CONTENTS (Continued)

	Page
Power Systems (continued)	
Jet Noise	153
Improved Propulsion Controls	153
Inlet Development	155
Nacelle Configuration Development	155
Thrust Reverser Development	157
Acoustic Lining Development	157
Optimized Nacelle Development	157
Nacelle/Airplane Development	160
Optimized Nacelle Development	160
Community, Aircraft and Ramp Noise	163
Auxiliary Systems	167
Hydraulic Power	169
Advanced Electrical Systems	174
Internal Engine Generator	178
Landing Gear Systems	178
Structural Carbon	184
Powered Wheel System	184
Pneumatic, Conditioning, and Protective Systems	188
Fuel System Improvement	190
Control of Flight	195
Application of Load Alleviating Controls to Configuration Optimization	197
Application of CCV Philosophy	197
Transonic Trailing Edge Controls Development	198
Development of Improved Atmospheric Models for Mesoscale Turbulence and Discrete Gusts	200
Flight Path Control System Development	203
Improved Aeroelastic Methods for Flight Controls Analysis	205
Advanced Navigation Systems Development	207
Advanced Digital Systems Applications	209
Advanced Flight Deck Development	212
Low Cost Inertial Sensors System	214
Air Traffic Control Terminal Operations and Airborne Requirement Study	217
Equipment and Facilities	221
Conceptual Approach	225
CONCLUSIONS	229
APPENDIX A	233
REFERENCES	245

FINAL REPORT

**STUDY OF THE APPLICATION OF ADVANCED TECHNOLOGIES
TO LONG-RANGE TRANSPORT AIRCRAFT**

VOLUME II

ADVANCED TECHNOLOGY PROGRAM RECOMMENDATIONS

ABSTRACT

The benefits of the application of advanced technology to future transport aircraft were investigated. The noise reduction goals established by the CARD (Civil Aviation Research and Development) study for the 1981-1985 time period can be satisfied. Reduced terminal area and airway congestion can result from use of advanced on-board systems and operating procedures. The use of advanced structural design concepts can result in greatly reduced gross weight and improved operating economics. The full potential of these benefits can be realized in a 1985 airplane by implementing a research and development program that is funded to an average level of approximately \$55 million per year over a ten year period.

SUMMARY

A study program was completed to evaluate the application of advanced technologies in all technical disciplines to the design of future long range transports. Social and economic goals established by the Joint DOT/NASA Civil Aviation Research and Development (CARD) study team formed the framework for the study. Evaluation included both technical and economic considerations. the study objectives were: (1) establish the payoff potential offered by application of advanced technology to future transports; (2) evaluate the state-of-readiness of attractive technology areas; and (3) recommend the action, including cost and schedule, required to bring the state-of-readiness to airplane program commitment status. Final results of the study are set forth in two volumes. Key results included in this volume are:

- The goals established by the CARD study team for noise reduction can be attained during the 1981-1985 time period. With the exception of nitrogen oxides, the same is true for emission reduction.
- Terminal area and airway congestion, considering predicted 1975-1985 traffic levels, can be substantially reduced by application of improved on-board systems and operating procedures. This will be true, providing compatible traffic control systems are implemented.
- The takeoff gross weight of a 200-passenger Mach 0.98 airplane designed to operational 1977 technology can be reduced by 12% and 30% for airplanes using advanced technology in operational use during 1981 and 1985, respectively. Composite structure, active controls, improved airfoils and lift/drag ratio are the prime contributors.
- Correspondingly estimated return on investment of 15.9% for the 1977 airplane can be increased to 17.7% and 20.5% for the 1981 and 1985 airplanes, respectively.
- The above benefits can only be realized if proper support is provided to pursue needed research and development. Over 50 individual programs were identified where state-of-readiness review indicated that recommended action, including funding and schedule, should be followed.
- A described broad front research and development program is recommended. The 10-year program involves all technical areas, governmental agencies and the airline, airframe, engine and supplier industries. An average funding level of approximately \$55 million per year is required to realize the full potential of the 1985 operational airplane.
- Flight vehicles required to demonstrate the adequacy and acceptability of advanced technology should take the form of modified existing transports. Their definition and demonstration should proceed in a manner that will permit the airframe and airline industry and government regulatory agencies to participate in the confidence building process. A described in-service evaluation and demonstration building block concept can be followed to that objective.

USE OF SI UNITS

Measurement values contained in this report are in both customary units and SI units with the former stated first and the latter in parentheses. The principal measurements and calculations have been made in the customary system of units.

INTRODUCTION

This document is the second of a two-volume final report covering the work that was accomplished by Boeing on NASA/Langley Research Center Contract NAS1-10703, "Study of the Application of Advanced Technologies to Long-Range Transport Aircraft." The work, which was accomplished by the Product Development organization of contractor's Commercial Airplane Group, began on April 23, 1971, and was completed on January 21, 1972. Recommended overall and individual research and development programs for advancement of those technologies identified in the studies are contained in this volume. Definition of the national need for such programs, assessment of the state-of-readiness of applicable technologies, specific recommended action including estimated cost and schedules, and an assessment of program adequacy and applicability to other aircraft programs are also provided. This volume contains the results of that portion of the study effort conducted under the following four subtasks of the Design Integration Task:

- "Identification of Advanced Technologies State-of-Readiness"
- "Identification of New Developmental Equipment"
- "Conceptual Approach"
- "Cost and Schedule"

STUDY OBJECTIVES AND SCHEDULE

The 9-month study was divided into two phases, Phase I and II, of approximate equal time duration. Figure 1 shows the timing of two primary activities pursued during both phases: configuration studies and advanced technology studies. The objectives of the configuration studies varied from Phase I to Phase II and are discussed in Volume I.

The advanced technology studies, results of which are contained in this volume, were pursued throughout Phases I and II, to the following objectives:

- Evaluate the need for and the payoff offered by application of advanced technology to future commercial transport design.
- Establish the state-of-readiness of advanced technology items that offered high payoff potential and/or high risk, including the definition of deficiencies which would preclude their immediate commitment to commercial transport design.
- Define the recommended action needed to overcome the deficiencies and bring the state-of-readiness to the point they could be committed to future transport programs, including estimates of the cost and schedule involved.

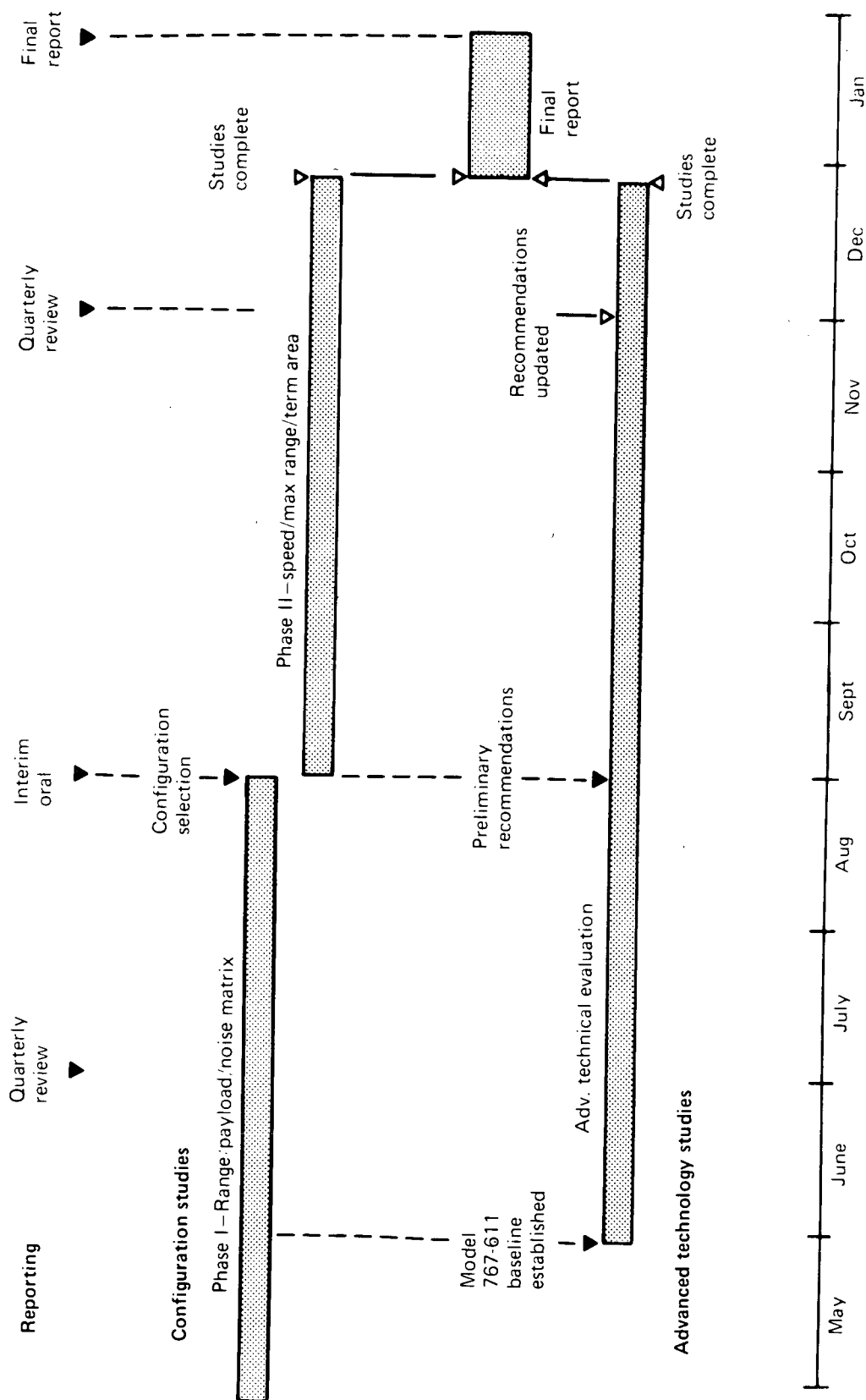


FIGURE 1.-STUDY SCHEDULE-CONTRACT NAS1-10703

- Identify the facilities and equipment including new or modified experimental flight vehicles required to demonstrate the adequacy of needed research and development effort to a status that would permit commitment by the airframe industry and acceptance by airlines and government regulatory agencies.

BACKGROUND AND RELATED ACTIVITIES

Reference is made to a significant effort conducted under a joint Department of Transportation (DOT) and National Aeronautics and Space Administration (NASA) team effort during 1970-1971. That study, entitled "The Civil Aviation Research and Development Study" (CARD) (ref. 1), was devoted to analysis of the past, present, and predicted future of U.S. civil aviation. The objective was to assess the current and future situation and determine the national benefits offered by healthy national civil aviation. The study resulted in the establishment of priorities for future research and development efforts to meet national social and economic needs, and identification of goals for that effort. These goals are consistent with the objectives of the contract Statement of Work that governed the work conducted by the contractor.

Supporting Work

Similar parallel studies have been conducted under contract to NASA/LRC by both Lockheed and General Dynamics (Contract Nos. NAS1-10701 and NAS1-10702). Advanced technology engine study work has been conducted by General Electric and Pratt and Whitney (Contract Nos. NAS3-15544 and NAS3-15550) in support of the airframe manufacturers' work. References to the engine company work will be found in appropriate sections of this volume.

Additionally, three supporting NASA/LRC contracts covering advanced technology transport development are noteworthy: Contract NAS1-10748, "Design, Construction, Wind Tunnel Testing, and Data Analysis of a Series of Optimized Parametric Models in Support of a NASA Advanced Technology Transport Program" (General Dynamics); Contract NAS1-10824, "Two-Dimensional Wind Tunnel Tests of a NASA Supercritical Airfoil with Various High-Lift Systems" (The Boeing Company); and Contract NAS1-10893, "Advanced Concept Secondary Power Systems for an Advanced Technology Transport Design" (The Boeing Company).

National Needs

The necessity of pursuing technology advancement programs for air transportation is directly traceable to national social, and economic needs. These needs include:

- Social
 - Reduction of noise and emission levels for improved environment
 - Provision of efficient public travel for minimum cost and time

- Economic
 - Enhance profitable airline operations through:
 - Reduction of hardware and operations cost
 - Reduction of congestion in terminal areas and airways
 - Ensure a favorable balance of trade considering potential foreign competition

Pursuant to the foregoing, three prime priority areas should be emphasized in technology advancement: (1) reduced noise/emissions; (2) reduced congestion; and (3) reduced costs. Reasons for this emphasis are discussed below.

Reduced Noise and Emissions

Stringent goals were established by the CARD study team relative to two major factors that affect the manner in which air transportation influences the quality of the environment: namely, noise and emissions. Recommended noise reduction goals for the future are shown by figure 2. Further, it was established that the ultimate goal should be to reduce aircraft noise to the point that it fades into the background noise level experienced by the general public. On the subject of emissions, specific maximum levels for emission of undesirable pollutants were established by the NASA for engine contractors during the parallel advanced engine studies. Attainment of the goals established for both noise and emissions will require concentrated research and development.

Congestion Reduction

Increased traffic has resulted in many of the major air traffic hubs becoming congested, with landing and takeoff delays becoming more and more prevalent. This problem can be expected to become increasingly worse with still further traffic increases. A similar situation is developing in the airway system. The knowledge and basic technology exists to minimize this problem. The ground and airborne hardware and procedures can become available if a limited amount of research and development is pursued. Research and development will define the interface requirements, the specific nature of the systems needed, and the demonstration of adequacy to the user and regulatory agencies. The public, the airport and airline operators would benefit by the results. The benefits would also include lowering of the noise level since some of the approach concepts applicable to congestion reduction are also effective in reducing noise.

Reduced Costs

The nation as a whole can benefit by advancements that would reduce hardware and operating costs. Advancements in the past have resulted in greater productivity such that the cost of air travel has remained below what would be expected from normal inflationary processes. In recent years, a plateau was reached followed by a limited increase in travel costs. There is sound reason to believe that potential advancements can be applied that can overcome what would probably be a continued increase in this cost. Although there may be some delay involved because of the need to incorporate special provisions for meeting noise and emission goals, every reasonable effort should be made to develop aircraft that will keep travel costs to a minimum.

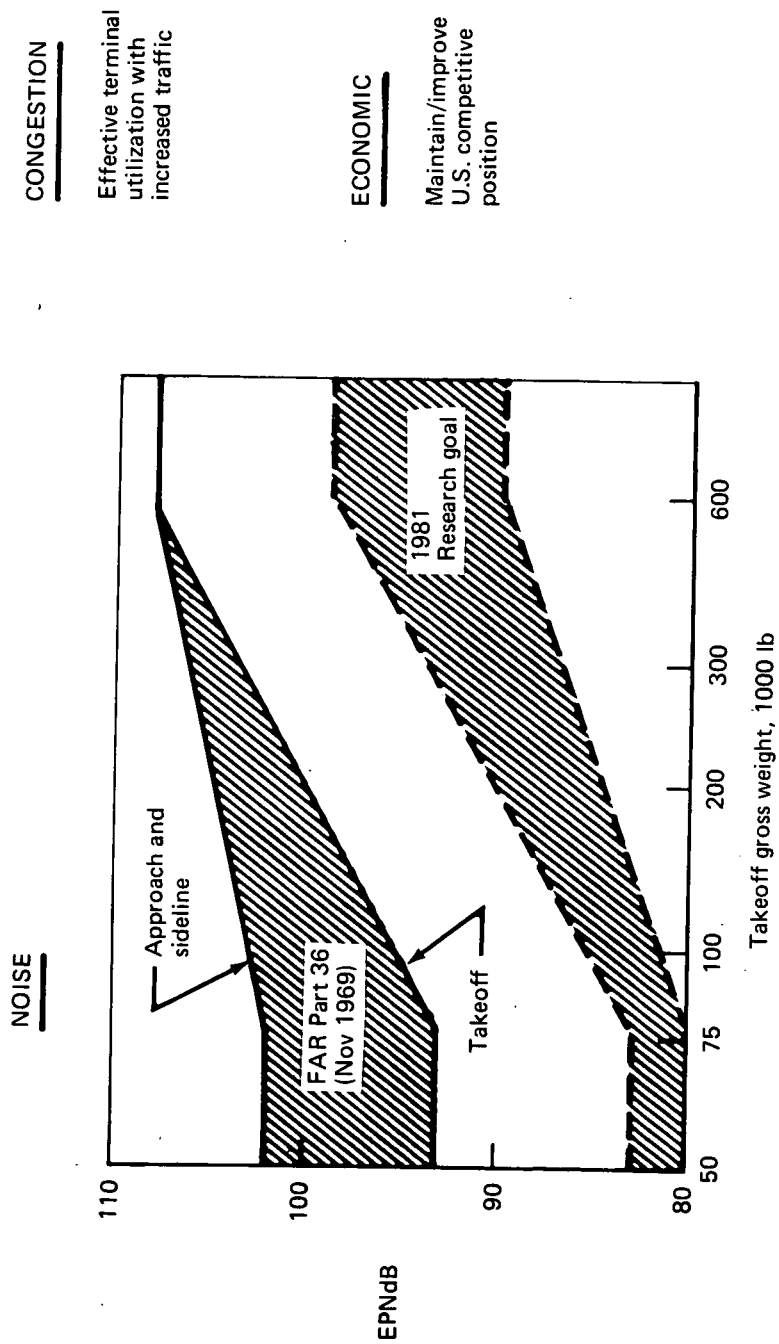


FIGURE 2.—GOALS—JOINT DOT-NASA CIVIL AVIATION R&D POLICY STUDY (CARD STUDY—MARCH 1971)

From the national standpoint the need to maintain a competitive position in the world-wide market is vital to the economic health of the nation. Continued export of aircraft to foreign markets and employment of the aerospace labor force are both at stake. Figure 3 shows the ratio of export/imports as experienced by the United States during the 1960 decade (ref. 2). From a very positive ratio during the early period there has been a significant decay since 1967. This has reached a point where the imports almost exceeded the exports during 1969-1970. Also shown is the contribution made by the sale of commercial aircraft products to foreign customers over the past few years. That contribution was sufficient to maintain a total export/import ratio value above unity.

Figure 4 gives some indication of why the total export/import ratio has declined. The automobile and electrical/electronic industries are examples of industries where foreign competition has increased so that a steadily decreasing ratio is occurring. More competitive foreign products are being imported that reduce United States industry sales to the domestic market. Also, the foreign market is being served less by United States industry.

Figure 4 shows a comparatively high ratio for commercial aircraft through the immediate future due to sales of DC-8, DC-9, 707, 727, 737, and 747 aircraft. However, this ratio could be threatened by the expanding foreign government support for highly competitive aircraft such as the A-300, Concorde, and TU-144. These will be introduced to passenger service in the 1973-1975 time period and improved versions can be expected around 1980.

Figure 5 shows total aerospace industry employment over the past several years (ref. 3). It reached a peak in 1968 due to the combination of space, military, and commercial aircraft programs. A continuous decline has occurred since that time. There is valid reason to expect that both domestic and foreign air travel will increase with a corresponding demand for additional equipment to satisfy both markets. Foreign governments recognize the benefits that derive when the demand is satisfied with their own products. They are, therefore, providing direct subsidy to their aeronautical industry to alleviate the large financial burden. This presents a situation where United States private industry has foreign governments as competitors.

Figure 6 reflects the total research and development support by the United States government (ref. 4) over the past decade, in terms of constant dollar value. The level increased through the mid-1960s with a decrease from that point on. The total values shown include research and development support to the aeronautical area by the military. This is of particular significance since before the period shown by figure 6, military funding was highly important to commercial programs through technology spinoff. An increasing portion of the military funding has been devoted to the missile and space area, with less to aircraft. The decay in aeronautical R&D activities has left a void.

To remain competitive in the face of growing foreign competition that is supported by respective government financial commitment, the United States must take appropriate action. Support of research and development through the recommended programs in this volume will fill the void that has occurred.

Source: Reference 2

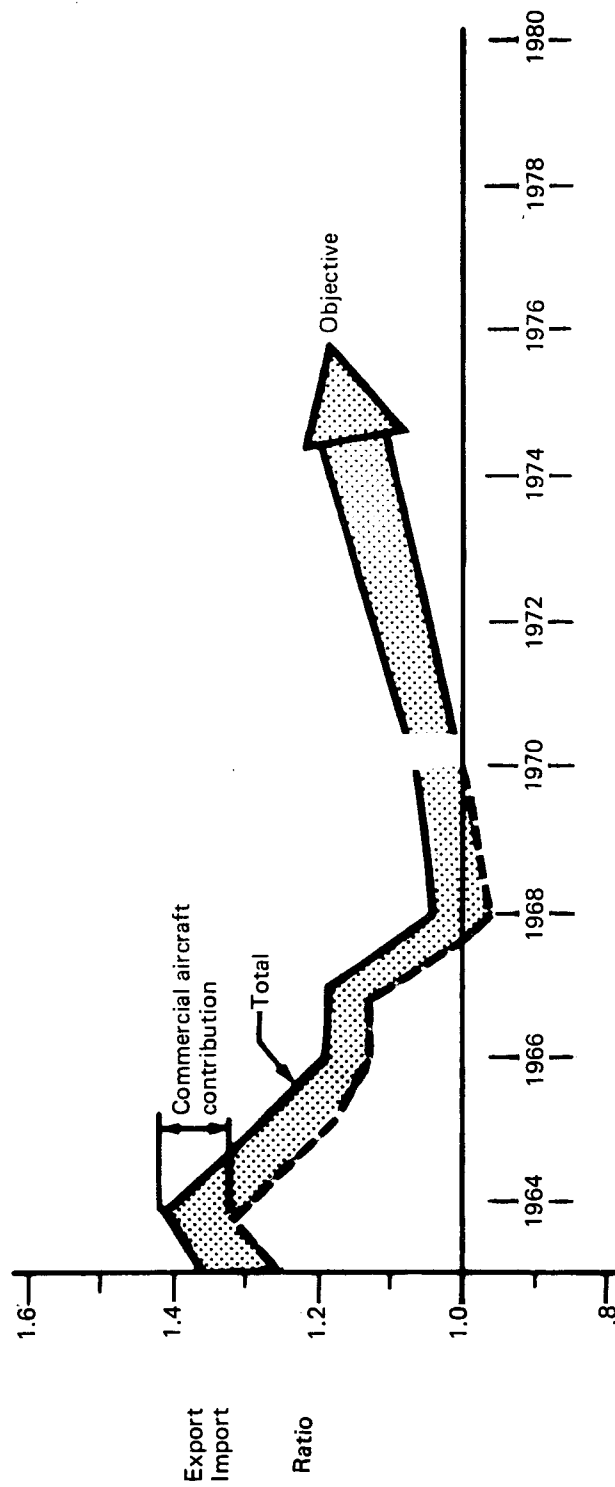


FIGURE 3.—U.S. BALANCE OF TRADE RATIO—TOTAL

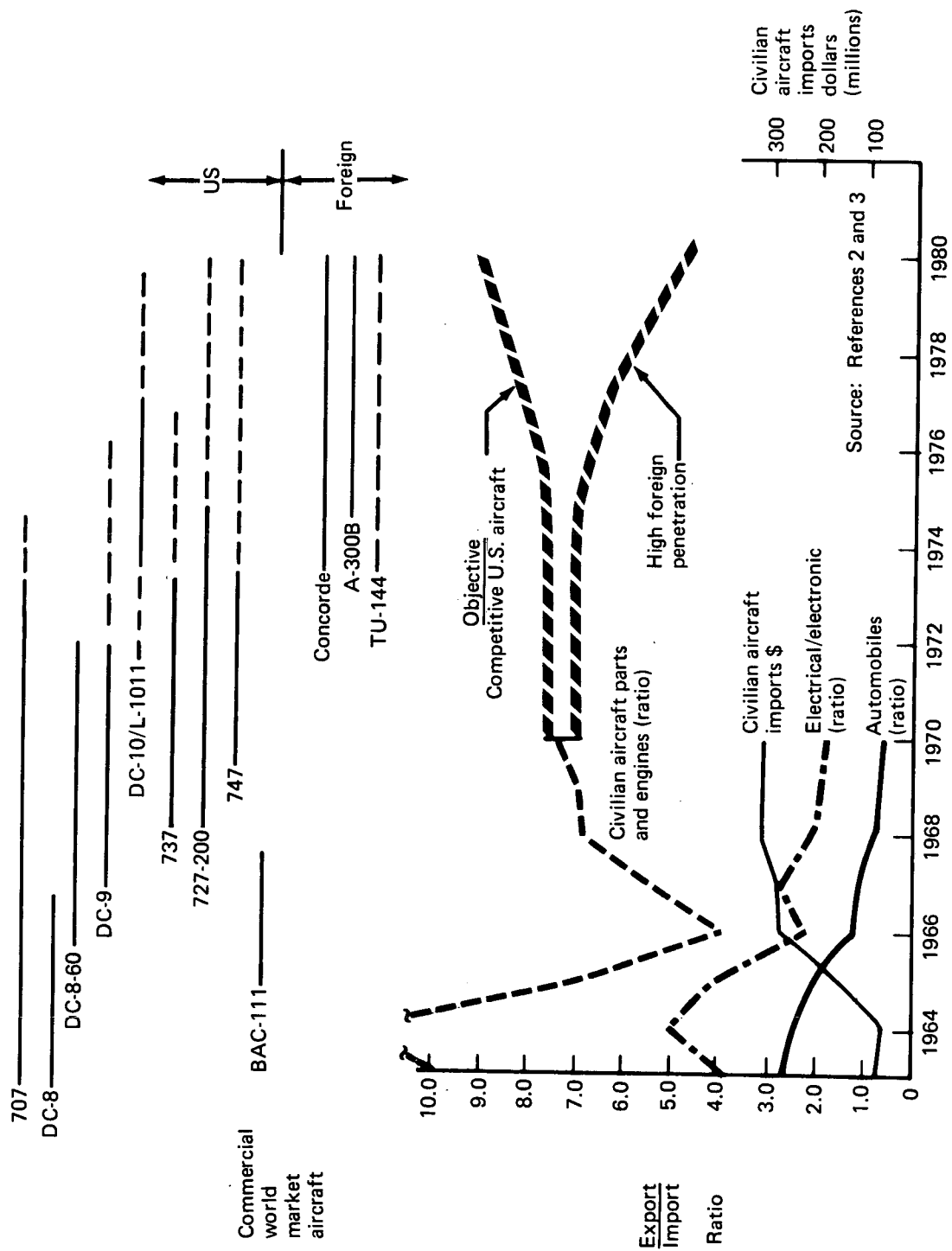


FIGURE 4.—EXPORT/IMPORT RATIO/EXAMPLE PRODUCTS

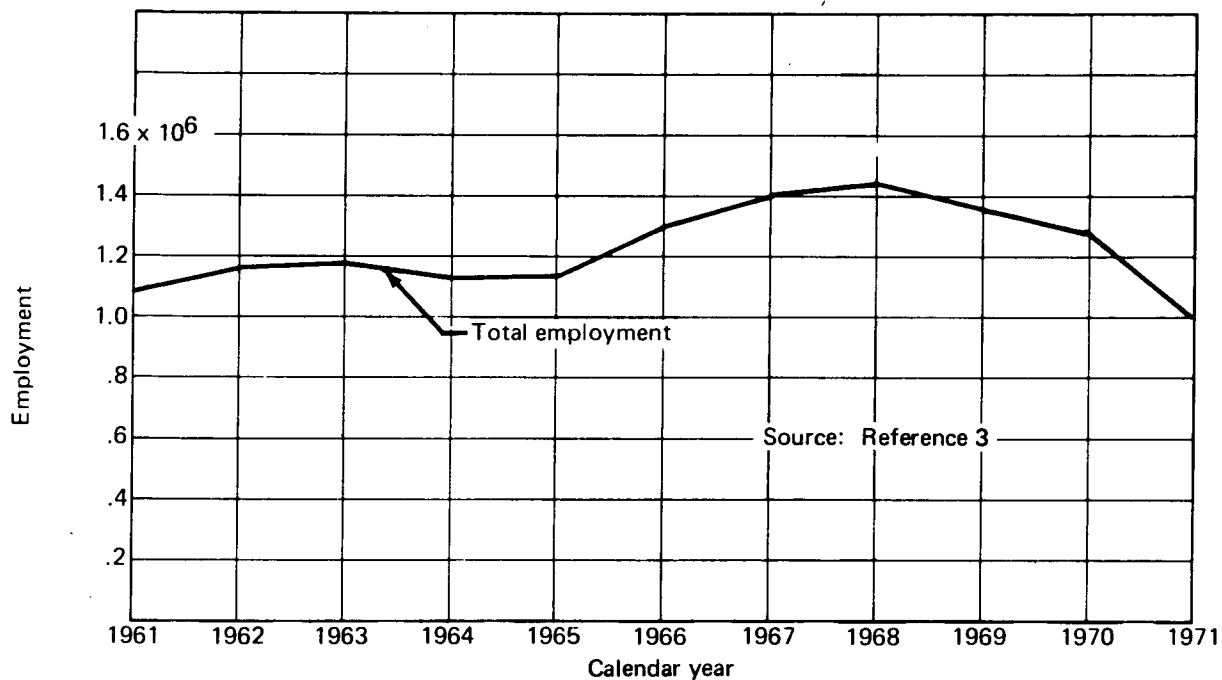


FIGURE 5.— AEROSPACE INDUSTRY EMPLOYMENT

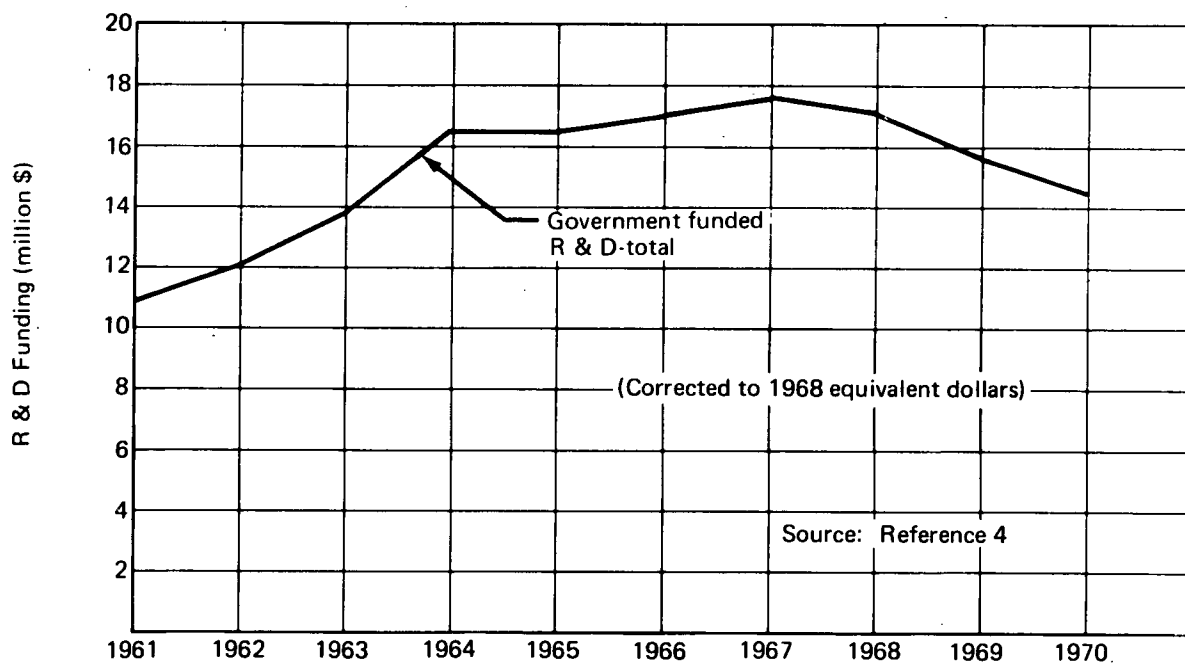


FIGURE 6.—GOVERNMENT SUPPORTER R&D FUNDING

GENERAL STUDY APPROACH

The logic flow involving six major activities that was followed during the study is presented in figure 7. The activities are discussed below.

Activity (1)—Baseline Configuration Definition

The Model -611 baseline configuration was defined early in Phase I as the configuration against which selected advanced technology items would be evaluated. This configuration is shown in figure 8 with key performance, technical, and economic characteristics shown in table 1. It was defined to a 3,000 nmi (5,560 kg), 40,000 lb (18,140 kg) performance capability and utilized the NASA three tail-mounted engine arrangement. Weight, cost, and performance, lift to drag, and SFC estimates were developed for this configuration based on use of what was considered current high confidence technology. This included use of supercritical airfoils, current 747/DC-10/L-1011 structure and systems, use of peripheral lining for noise attenuation, essentially current engine technology, and a balance philosophy revised from current practice. It represents an airplane that could be introduced into commercial service in 1977. The performance and economic sensitivity to design variations of the Model -611 was developed.

Activity (2)—Advanced Technology Identification

Potential advanced technology candidate items in each technical discipline were identified for detailed evaluation.

Activities (3)—Evaluation and (4)—Quantification

A study was conducted on each identified technology item to determine if it offered a potential payoff in the form of increased performance through reduced weight, drag, SFC, noise, congestion; or improved maintenance and reliability. When a safety input was involved, it was evaluated to ensure no compromise. When possible, the economic impact of a particular item was identified where possible. Specific items offering a payoff were isolated and evaluated as to the state-of-readiness and need for research and development. This provided the foundation for defining the nature of research and development programs and their cost and schedule required to bring them to a state-of-readiness that would permit them to be committed to a new airplane program. Cross plots of the quantified payoff versus the cost of needed research and development permitted evaluation of the relative leverage that each item offered. This concept is shown in figure 7 and is discussed in more depth in the Integrated Program section. Individual program schedules were also developed to determine when the various technology items could be made available.

Activity (5)—Integrated Advanced Configuration Definition

The scheduling studies noted above resulted in identification of two significant time periods (1981 and 1985) when major advances could be introduced, providing that the necessary research and development is started and carried out as scheduled. The Phase II configuration studies were devoted to a single configuration, Model -620, that was similar to the initial Model -611 status baseline configuration. The Model -620 was defined using advanced

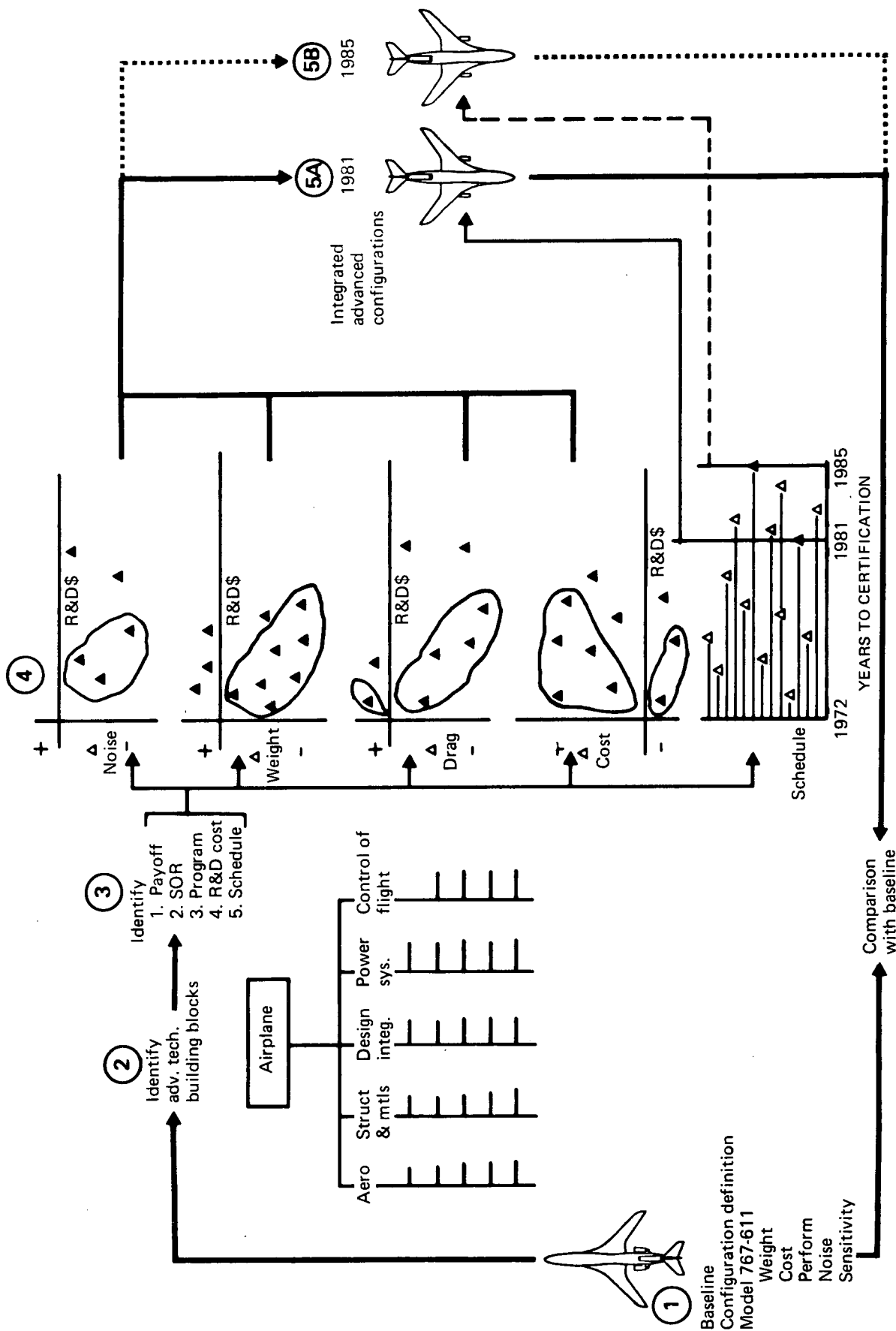


FIGURE 7.—ADVANCED TECHNOLOGY STUDY FLOW

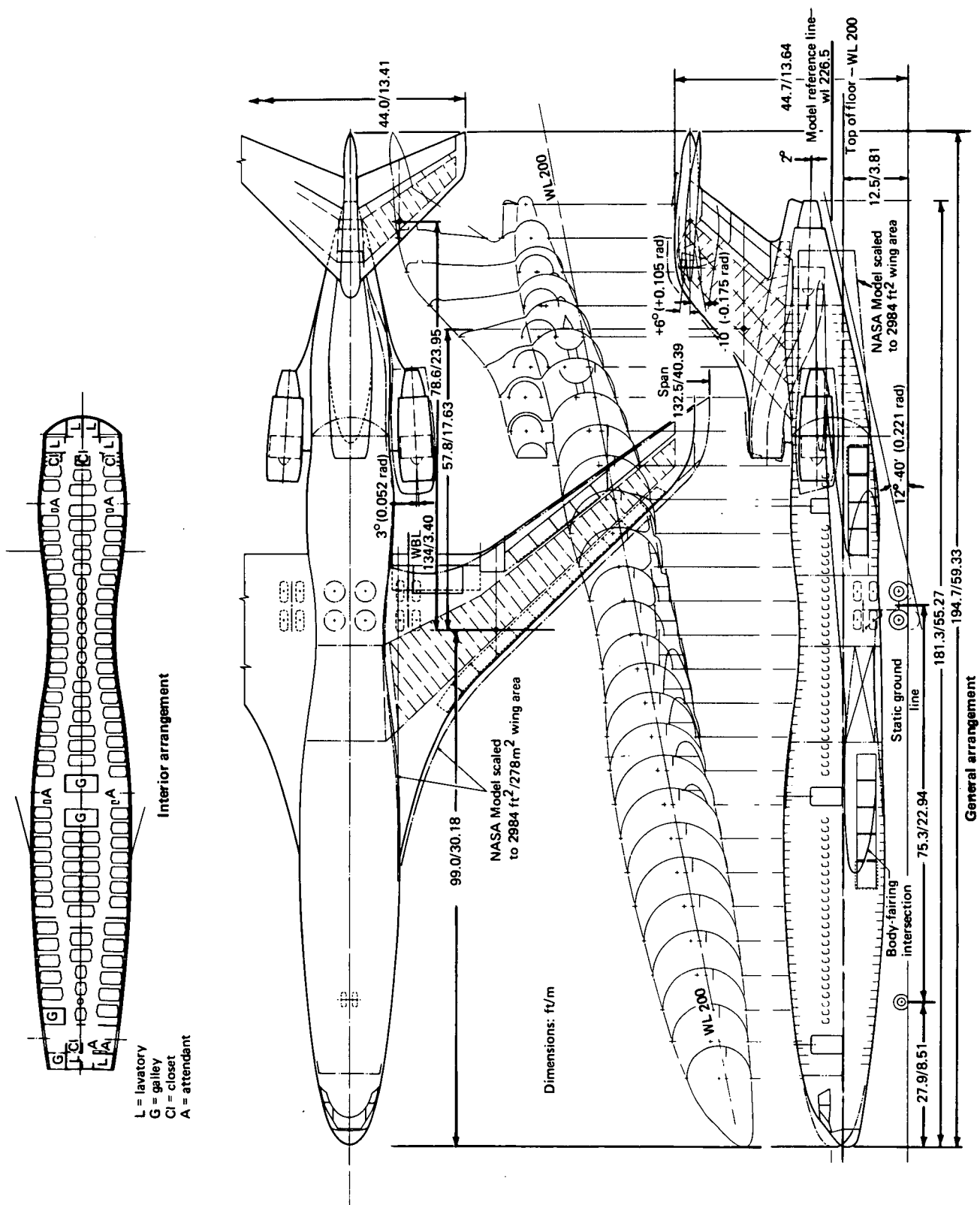


FIGURE 8.— GENERAL ARRANGEMENT — NASA CONFIGURATION — MODEL — 611

**TABLE I—MODEL 767-611 ADVANCED TECHNOLOGY TRADE
STUDY BASELINE CHARACTERISTICS**

Configuration Subject	Model 767-611 Advanced Technology trade study baseline
Potential certification date	1977
Speed: Mach no.	.98
Engine arrangement	3 tail mounted engines
Range Payload	1
Takeoff gross weight	356,000 lb (173,000 Kg) 2
Noise level (traded EPNdB below current FAR Part 36	-5.2
Economics—ROI % at 1000 nmi and 0.55 LF	Baseline
Technology	
Aerodynamics	Supercritical airfoils and area ruling
Structures	Current aluminum
Control of flight	Unstable with near optimum c.g.
Operations	2 segment, decelerating straight-in approach
Propulsion	ATSA-4-2800-24 30% improvement in attenuation effectiveness



Range 3000 nmi (5560 km), Payload 40,000 lb (18,140 Kg)
Objectives were basis for initial airplane performance characteristics
used for advanced technology trade studies. Estimated weights are
based on an uncycled airplane.



See Volume I for weight breakdown.

technology conclusions resulting from Phase I studies. It represents use of the major advanced technology items that could be applied to an operational 1981 airplane. It is described in Volume I and differs from the Model -611 by use of two wing- and one tail-mounted engine instead of three tail-mounted engines. Although as a result of Phase II redirection a 1985 configuration was not defined, the applicable technologies were identified.

Activity (6)—Comparison With Baseline

Comparison of the baseline configuration with other configurations that incorporate advanced technology items permitted assessment of the benefits that can be attained. Although they differ because of engine placement, a comparison between the 1977 operational Model -611 and the 1981 operational Model -620 permits high confidence assessment of benefits for the 1981 period. Estimated benefits were also determined for the 1985 airplane. These comparisons are discussed in the assessment portion of the Integrated Program section.

The above activities resulted in the identification of over 50 individual items deserving future effort. These are described in the Recommended Action section with a total program overview provided in the Integrated Program section.

BASIS FOR RECOMMENDED PROGRAM

The Recommended Action section of this volume contains an estimated cost and schedule for a number of advanced technology research and development items. In nearly all cases, costs and schedules are based on the assumption that a single government, industry, or academic organization would take the recommended action. Where the contractor considered that it was desirable that more than one organization should pursue the effort, it is so noted. Other items may well deserve the attention of more than one organization for multiple parallel approaches, or joint or associate relationships might be desired. Both the costs and schedules noted for each item should be re-evaluated if multiple approaches are taken.

Estimated costs for the recommended research and development efforts represent the contractor's best efforts to identify all costs associated with the individual programs. The ability to develop such costs was largely a function of the depth of program definition that was permitted by study budget constraints. The contractor recommends that a tolerance be applied to all program item costs when considered individually, particularly where a non-airframe industry organization would be involved.

All recommended schedules are based on the time required to bring the state-of-readiness to a point where it would be feasible to commit specific technology items to a new airplane program. Additionally, airplane program schedule estimates were prepared in accordance with the Statement of Work. This requires that a period of 5 and 6 years be allowed for the time between technology commitment and airplane certification for airframe and propulsion, respectively.

SYMBOLS AND ABBREVIATIONS

Amp	Ampere
APU	Auxiliary power unit
	Aspect ratio
ATC	Air traffic control
$A_{\text{wet}}, S_{\text{wet}}$	Wetted area
B.L.C.	Boundary layer control
\bar{C}	Mean aerodynamic chord length (see also MAC)
CAS	Collision avoidance system
C_D	Drag coefficient
$C_{D_{P_{\text{min}}}}$	Airplane parasite drag coefficient
$C_{D_{\pi}}$	Drag coefficient based on frontal area
cg	Center of gravity
C_j	Thrust or blowing coefficient
C_L	Lift coefficient
C_{m_0}	Pitching moment coefficient at zero lift
C_N	Normal force coefficient
C_P	Pressure coefficient
dB	Decibels
d_{hilite}	Cowl hilite (leading-edge) diameter
DOC	Direct operating cost
DOT	Department of Transportation
D_{MAX}	Cowl maximum diameter
DME	Distance measuring equipment

D_{sting}	Sting diameter
EPNdB	Unit of effective perceived noise level
FR	Fineness ratio (length-to-diameter ratio) (see also L/D)
g	Acceleration of gravity
IFR	Instrument flight rules
K	Thousand
K_g	Kilograms
KVA	Kilovolt amperes
L	Cowl or body length
lb	Pounds
lb/in.^2	Pounds per square inch
L/D	Lift-to-drag ratio; fineness ratio
LORAN	Current radio navigation system
M	Mach number
m	Meters
MAC	Mean aerodynamic chord (see also \bar{C})
MLS	Microwave landing system
MTBF	Mean time between failures
N	Newtons
N/m^2	Newtons per square meter
OMEGA	Long range hyperbolic navigation system
P_{∞}	Free stream static pressure
PNdB	Unit of perceived noise level
P_T, P_t	Total pressure

$P_{t\infty}$	Free-stream total pressure
SOW	NASA statement of work L17-1533
t/c	Thickness ratio
TOGW	Takeoff gross weight
VOR	Very high frequency OMNI range
\dot{W}	Inlet weight flow
X	Body or cowl station
X/L	Body or cowl station expressed as a fraction of total length
α_w	Wing angle of attack
δ_F	Flap deflection
$\Lambda_{C/4}$	Wing sweep at the quarter chord

INTEGRATED PROGRAM

Summary data and discussion in this section provides an overview of the total recommended program. More detailed coverage of individual advanced technology program items is contained in the Recommended Actions section that follows.

PROGRAM SCOPE

Without exception, all technical disciplines were found to offer potential benefits pursuant to the goals outlined in the Introduction. Therefore, a broad front research and development program involving all technical disciplines is recommended. The scope of the total program is indicated by figure 9, which lists the titles of the over 50 individual programs that are recommended. The program is defined in a form that should involve an integrated joint effort by the NASA, the airframe, engine and airline industries, and government regulating agencies.

Several of the recommended programs are related and depend upon each other for maximum benefit. Because of these factors, it is recommended that a central integration activity be included as part of the total effort. A program for this purpose is described and included in the cost and schedule estimates.

SIGNIFICANT ITEM PAYOFF POTENTIAL

Individual advanced technology items show varying types of potential payoff or benefit. Generally, the payoff was measured quantitatively in terms of weight, cost, or noise reduction potential.

Cost and Weight Payoff

To evaluate the cost effectivity of individual candidate items, sensitivity curves as shown by figures 10 and 11 were developed for the Model -611 baseline configuration. These figures show the effect on manufacturing cost and lifetime operating cost for incremental changes in various parameters.

A parameter was selected as the indicator which best measures the relative economic worth of incorporating advanced technology options. This parameter, total value, is defined to be the sum of the net change in manufacturing cost and the savings of cash direct operating cost over the operating life of the airplane. The method used for computing total value is explained in the appendix.

Figure 12 depicts total value levels for several representative technology items with the required research and development cost for their development. The chart shows the relative merit of several candidate options. Weight savings resulting from the same technology items are shown in figure 13. A different priority results in some cases, depending on whether weight or total value is the principal evaluation parameter. In either case, figure 12 indicates

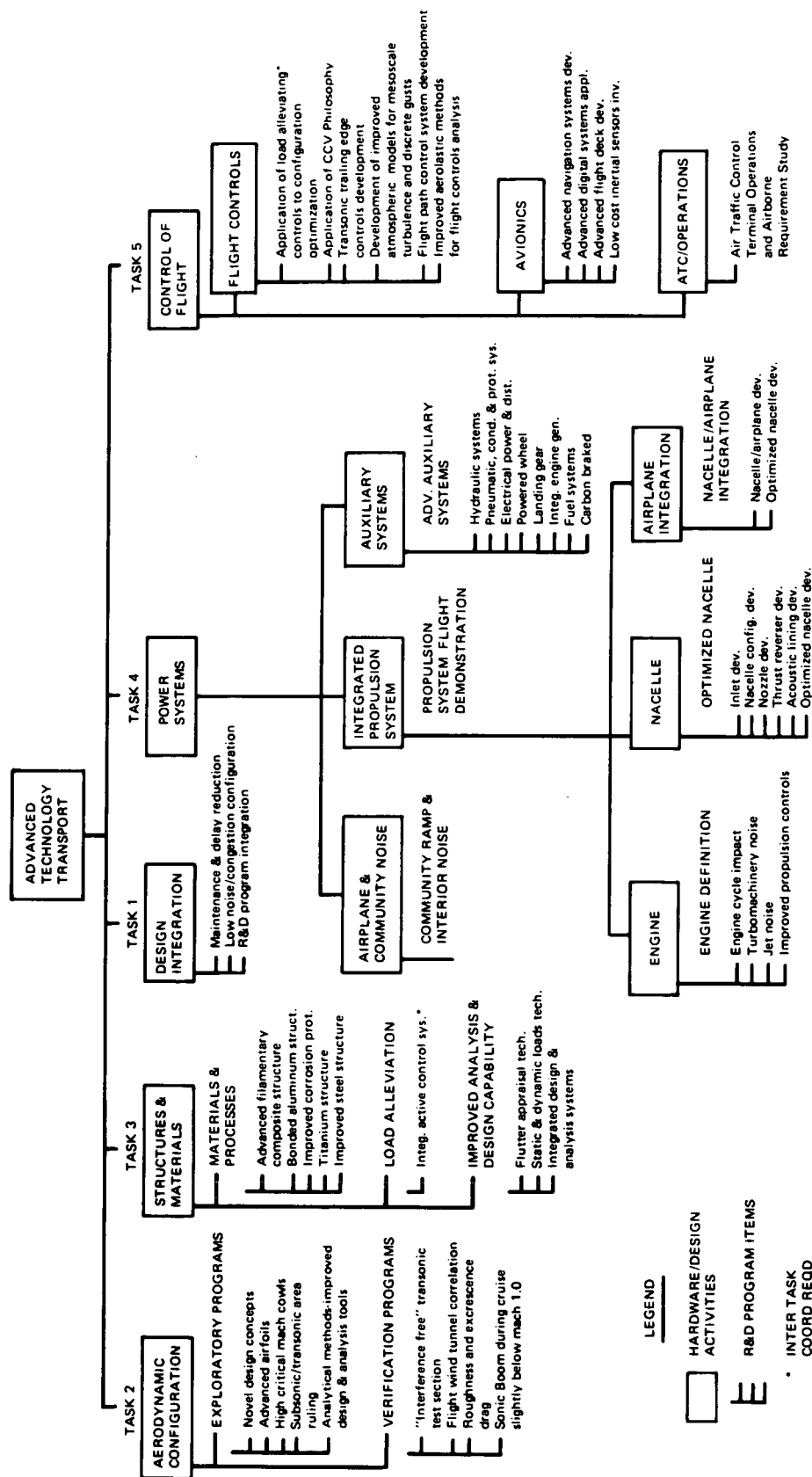


FIGURE 9.—ADVANCED TECHNOLOGY ITEMS

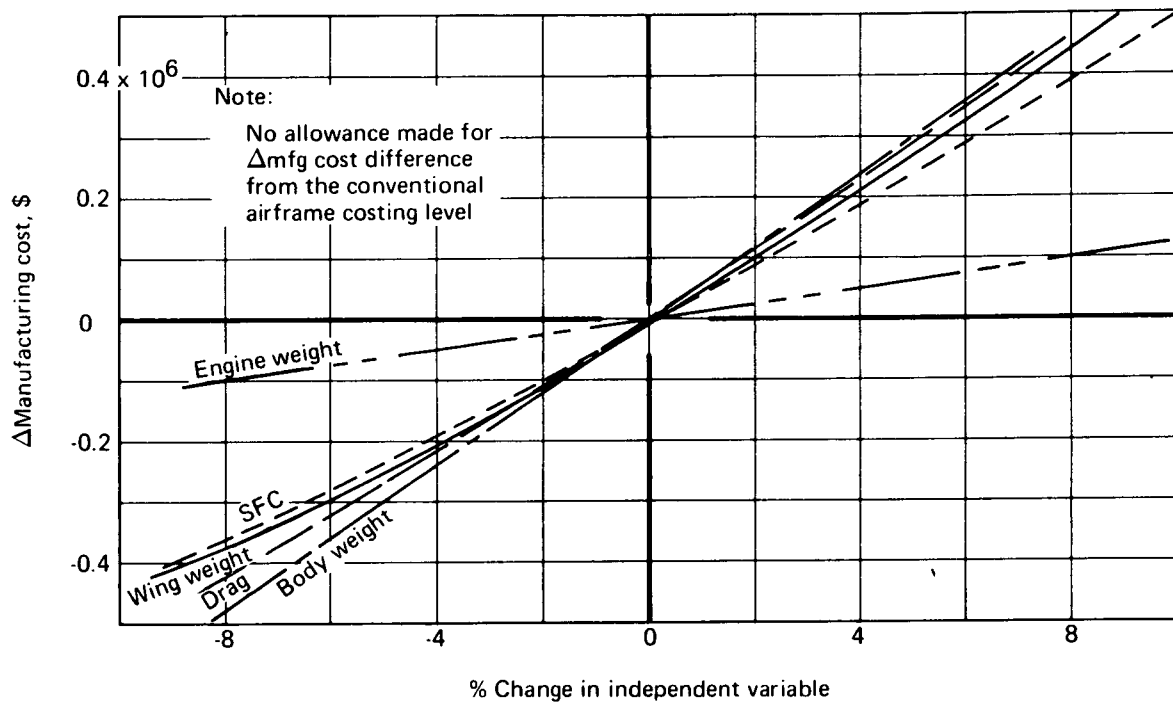


FIGURE 10.— MANUFACTURING COST SENSITIVITY,
 $M = 0.98$, 195 Seats, 2870 n mi (5320 km) Design Range (ATA)

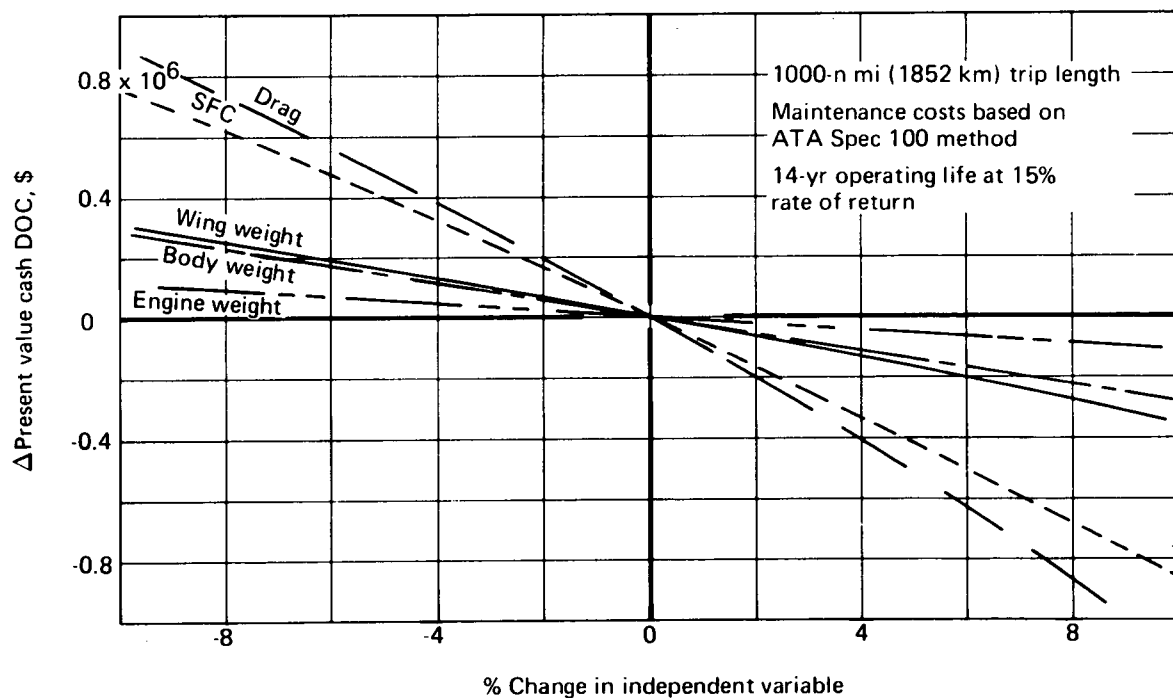


FIGURE 11.— CHANGE IN PRESENT VALUE OF LIFETIME CASH DOC,
 $M = 0.98$, 195 Seats, 2870 n mi (5320 km) Design Range (ATA)

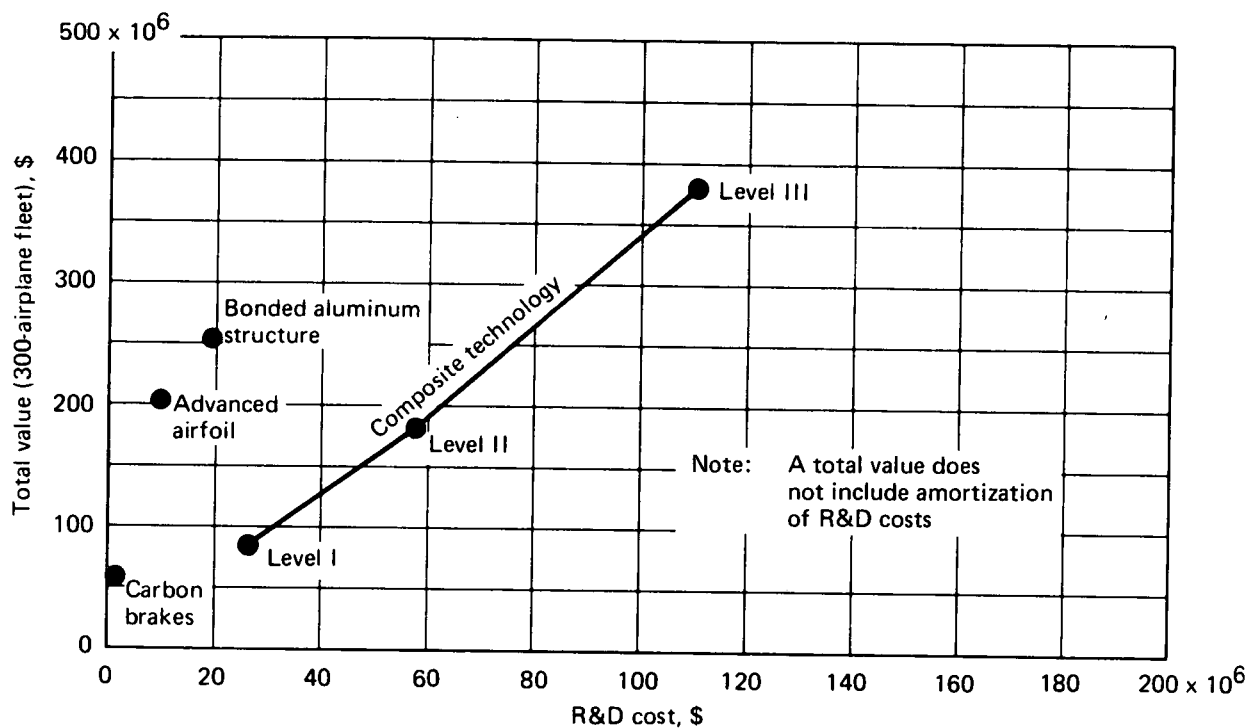


FIGURE 12.— ADVANCED TECHNOLOGY DEVELOPMENT—COST VS PAYOFF

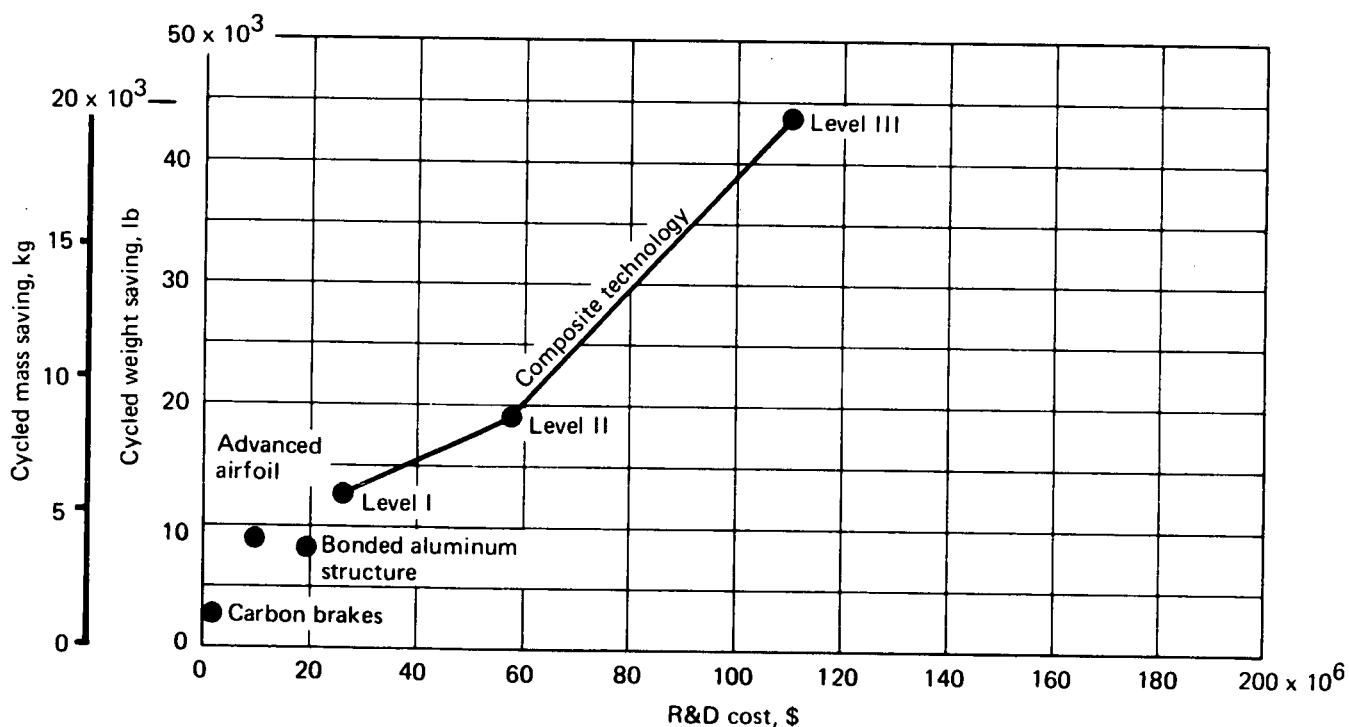


FIGURE 13.— ADVANCED TECHNOLOGY DEVELOPMENT—WEIGHT SAVED VS COST

there are several technology options noted that appear attractive based on their total payoff relative to the modest R&D dollars required. Bonded aluminum structure and the advanced airfoil development are among those in this category. However, most of those have a modest weight payoff. Level 3 composite structure development shows a large potential return in both weight and total value. A summary of the analysis results for each candidate improvement is included in the appendix.

A further indication of the relative payoff presented by addition of advanced technology is shown by figure 14. This reflects the estimated effect on ROI by: (1) noise reduction to 10 and 15 EPNdB below current FAR Part 36; (2) simultaneous addition of advanced composites and active controls at noise levels consistent with current FAR Part 36; and (3) simultaneous addition of advanced composites, active controls and noise reduction to FAR Part 36 minus 10 EPNdB and minus 15 EPNdB. Individual benefits or penalties are not necessarily directly additive because of airplane resizing effects. Two potential ROI levels are shown where advanced composites are applied. The first level, shown by the solid line bar, reflects best estimates of the cost to fabricate advanced composite structure. The higher ROI, shown by the dashed bar, would result if advanced composites could be included at the same cost as conventional aluminum structure. In either case, it can be seen that composite structure and active controls overcome the penalties imposed by noise reduction of 10 EPNdB and largely overcome the effects of reduction to 15 EPNdB below current FAR Part 36.

Noise Reduction Payoff

The degree of noise reduction that can be attained in the propulsion area versus the recommended research and development funding can only be estimated with a relatively large degree of tolerance. This area presents the largest realm of unknowns and lack of refined analysis methods. The relatively large portion of the recommended total program funding that is applicable to this area reflects the need for organized and concentrated effort to overcome these deficiencies. Figure 15 shows a range of noise reduction that can be attained through research and development for five propulsion items. It is pointed out that the values shown are not directly additive. Estimated noise reduction potential through revised operational procedures is also shown in figure 15. This benefit would be approximately additive to that available from propulsion noise reduction.

Related Program Payoff

Review of all of the recommended programs, considering the needs in other aeronautical and space field, resulted in the evaluation shown by figure 16. The degree of applicability of each recommended program was measured against the needs of various speed ranges and types of flight vehicle development. An assessment was made of the degree to which the recommended program would impact, or satisfy those needs. The results show that the Structural and Control of Flight programs offer large payoff potential in both respects. The propulsion programs are applicable and satisfy two vital areas, subsonic/STOL and combat airplanes. Similarly the noise reduction programs present good payoff potential in several key areas. The aerodynamic programs, being postured to the transonic speed range, offer limited application and impact.

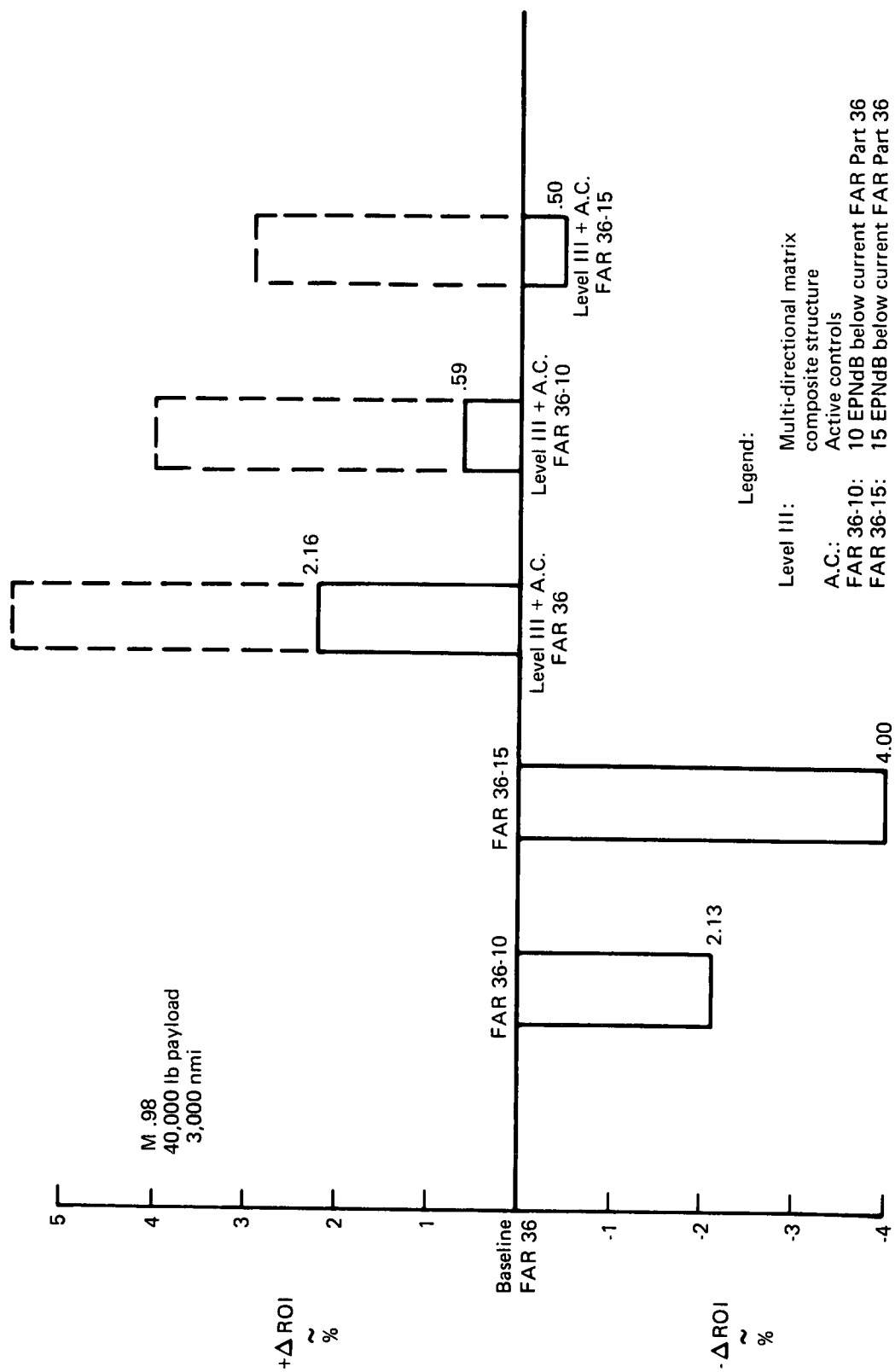


FIGURE 14.—RETURN ON INVESTMENT

- The graph depicts the separate noise goal and the estimated portion of the total R&D costs that contribute to noise reduction for each of the individual programs described by the propulsion portion of the power systems section.

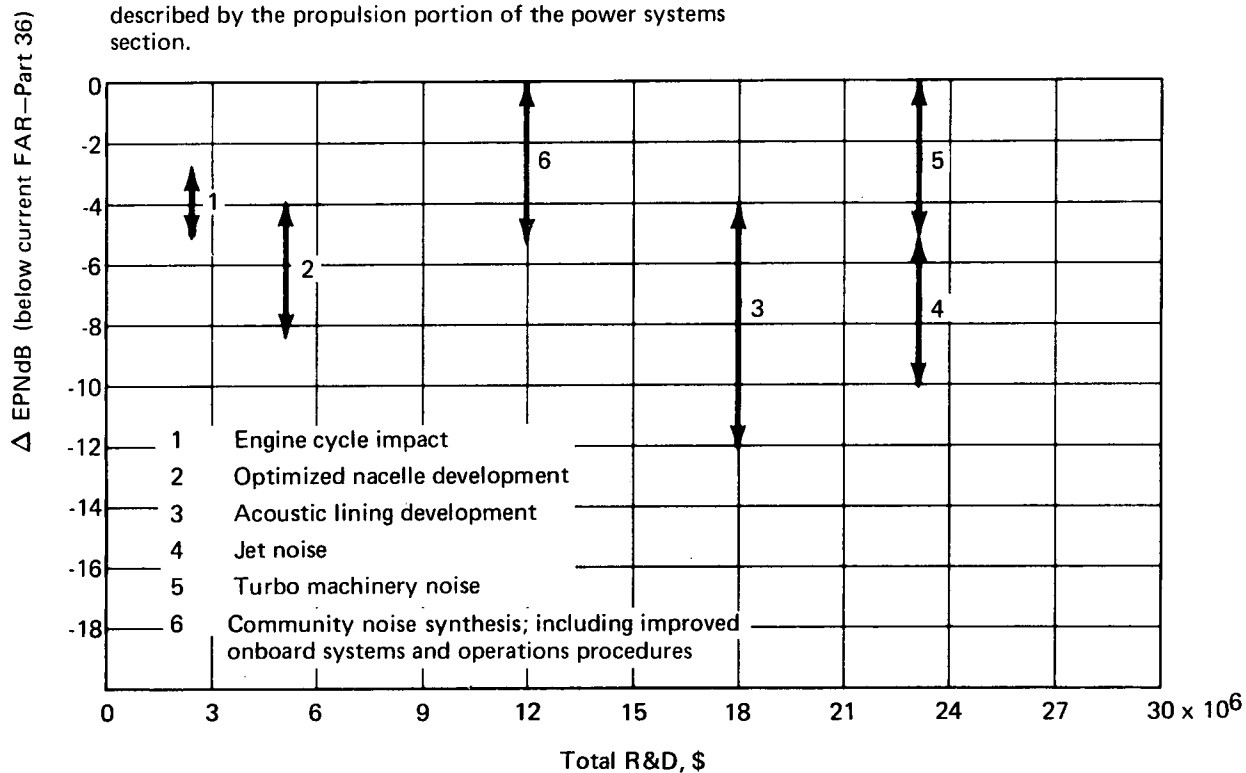


FIGURE 15.—ADVANCED TECHNOLOGY DEVELOPMENT—NOISE REDUCTION

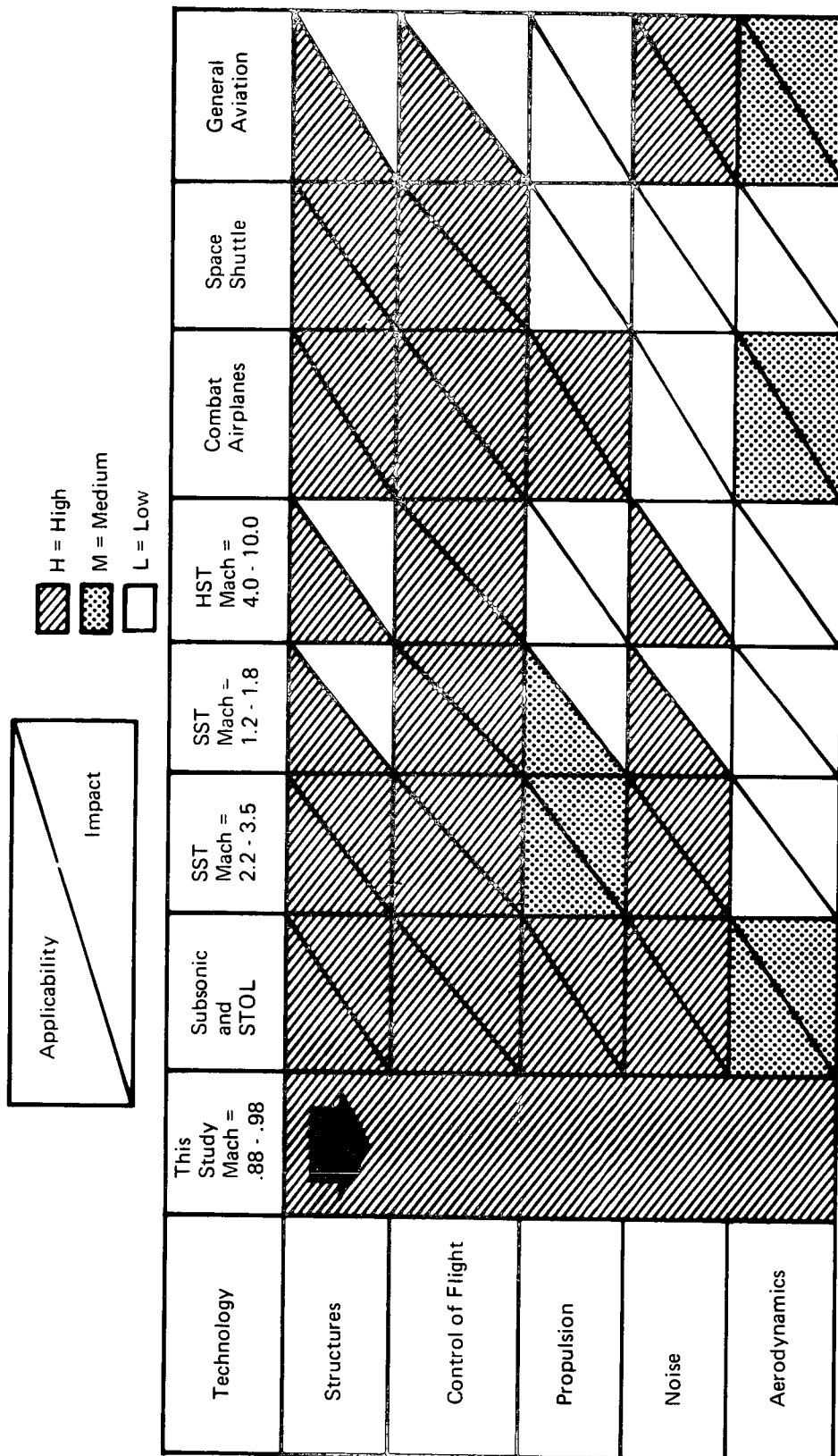


FIGURE 16.—APPLICABILITY AND IMPACT OF PROPOSED
ADVANCED TECHNOLOGY PROGRAMS TO OTHER AIRPLANES

Figure 16 is limited to areas of aerospace interest. Additional "spinoff" benefits for non-aerospace uses can be expected. Advanced composites, carbon brake, and bonded aluminum programs can be expected to provide benefits to the building, general transportation, and equipment industries. Likewise, some of the noise reduction work may benefit industrial noise reduction efforts.

STATE-OF-READINESS

Each advanced technology candidate item that offered attractive payoff potential was reviewed to determine if high risk areas were present or if deficiencies existed that precluded the item from immediate commitment to an airplane program. This included a review of the status of development as known to the contractor. The schedule required to overcome any deficiencies was determined. The resulting schedules provide a quantitative measurement of the state-of-readiness as shown in figure 17. The data show the estimated certification dates for new airplanes using key technology items. With an immediate go-ahead, the state-of-readiness is such that significant time periods are involved before items can be introduced. A year-for-year slide can be expected if necessary funding to support required programs is delayed.

Figure 17 is based on the assumption of a 5- and 6-year lead time period being required from commitment to certification for airframe and propulsion elements, respectively. It is possible that the 5- and 6-year commitment to certification lead time could be reduced. On the other hand, unknown problems could extend the research period. Even with immediate availability of program funding, it is significant that some of the higher payoff items can only be made available at the time when foreign competition is expected to be the highest.

TOTAL PROGRAM COST AND SCHEDULE

An approximate one-half billion dollar program, scheduled for expenditure over a 10-year period, is recommended. The 50 million dollar per year average would be a nominal amount considering the benefits that would accrue. Total and individual funding for five major technical areas are shown by figures 18 through 24. Figures 19, 20, 21, 22, and 23 show the funding, by fiscal year, for each area as a function of years from go-ahead. Figure 24 provides cumulative funding on the same go-ahead basis. Further breakdown of the estimated costs to the individual program level is provided in the introduction to the Recommended Action section of this volume. Still greater detail is provided as a part of each individual program description. In all cases, the funding values reflect contractor "best estimates" that include required costs for engineering analysis and design, development hardware fabrication, facilities and equipment and all required testing. They do not include premium costs for an accelerated schedule.

A schedule overview for major elements of the program is shown in figure 25. The shaded portion of each schedule bar reflects the research and development period estimated for the major element. Detailed schedule estimates are provided as a part of each program item described in the Recommended Action section of this volume.

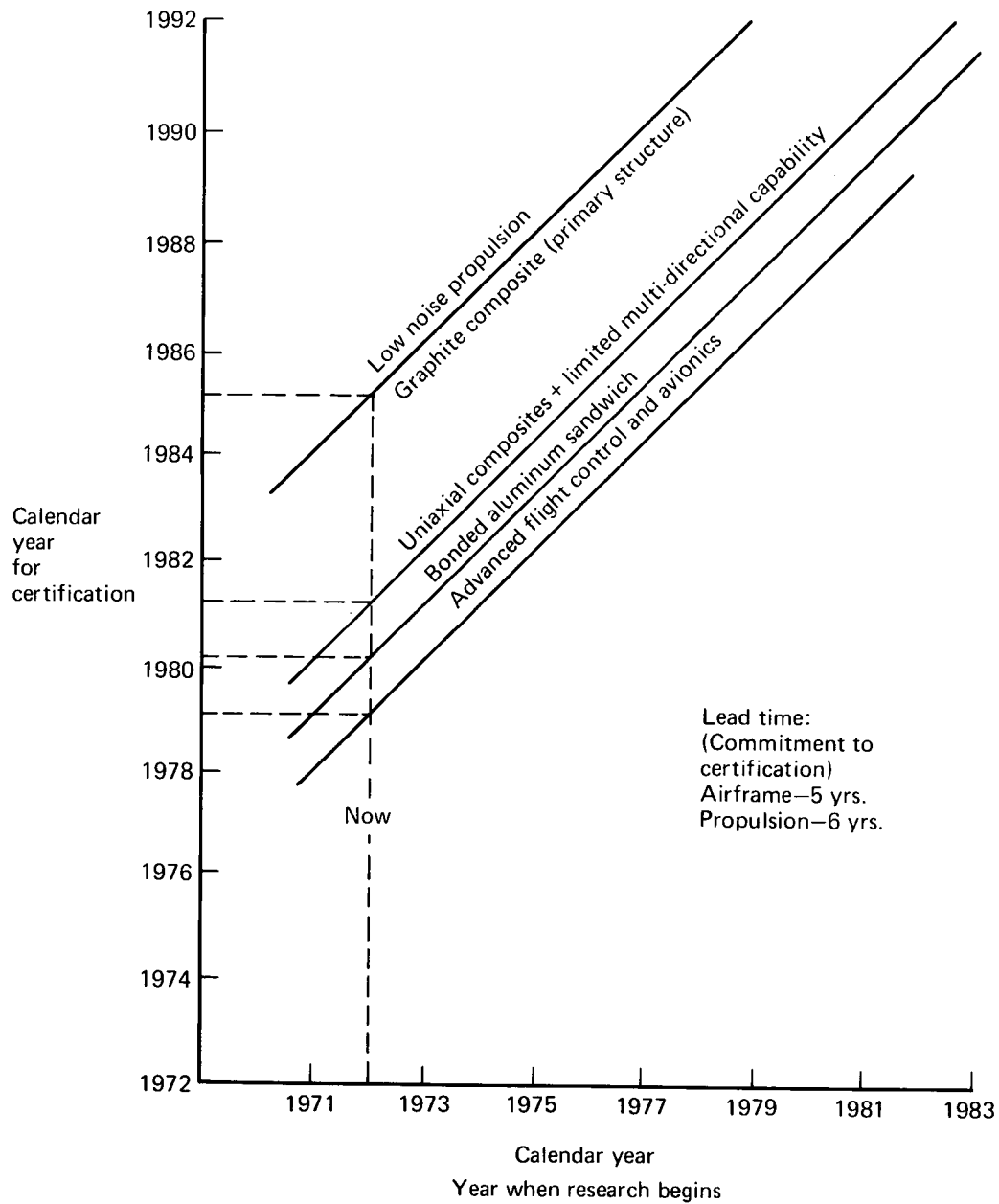


FIGURE 17.—STATE OF READINESS OF TYPICAL ADVANCED TECHNOLOGY ITEMS

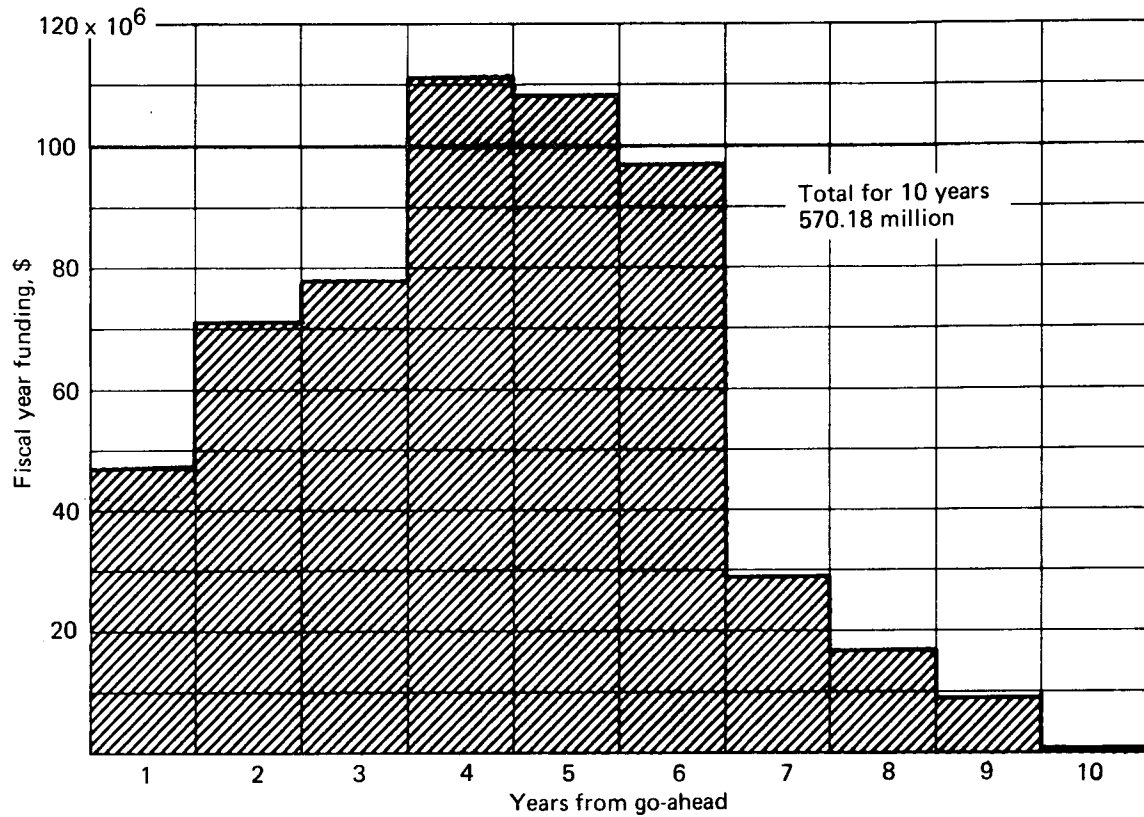


FIGURE 18.—TOTAL PROGRAM

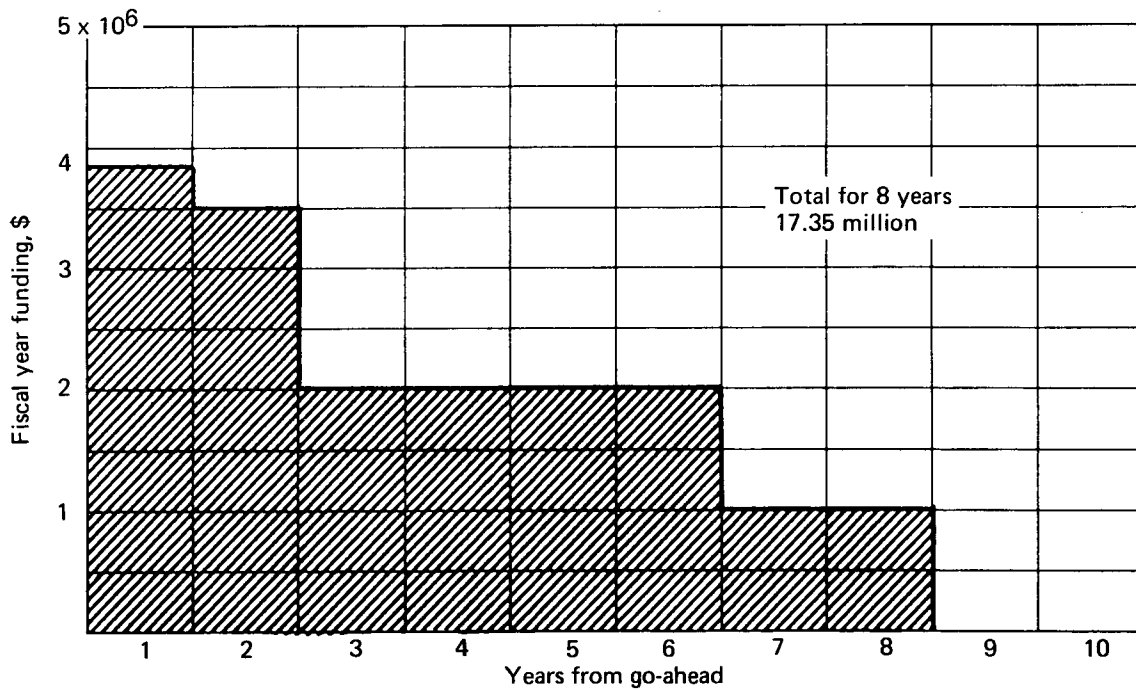


FIGURE 19.—DESIGN INTEGRATION

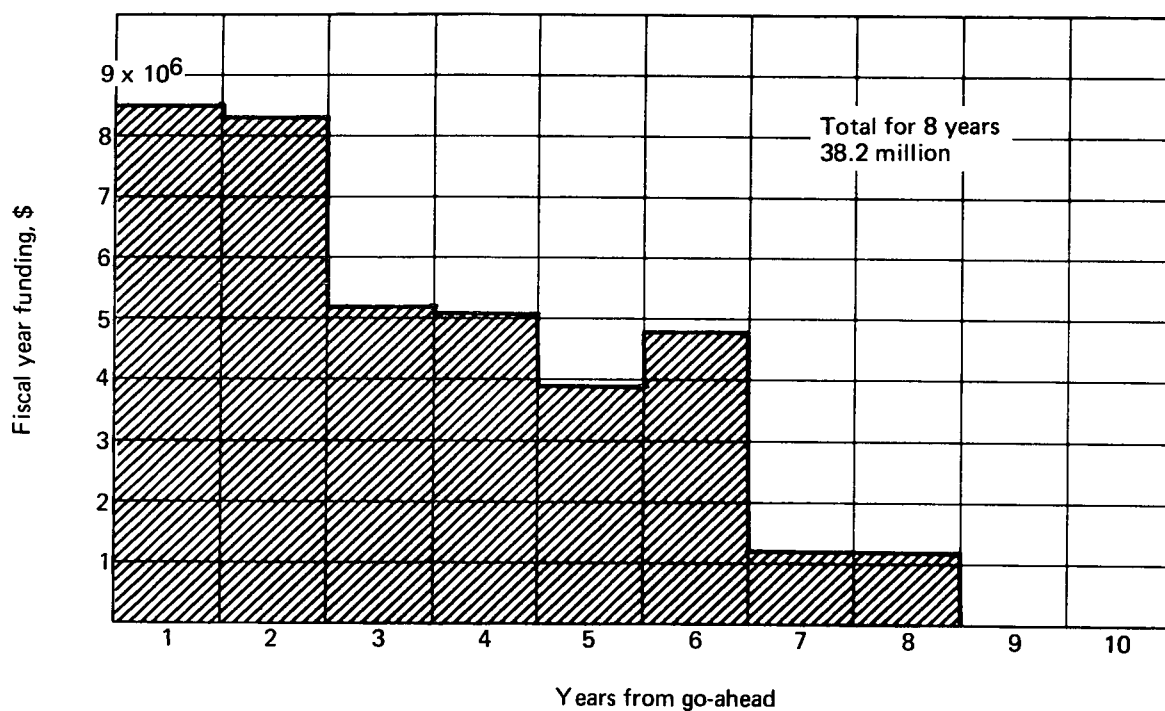


FIGURE 20.—AERODYNAMIC CONFIGURATION

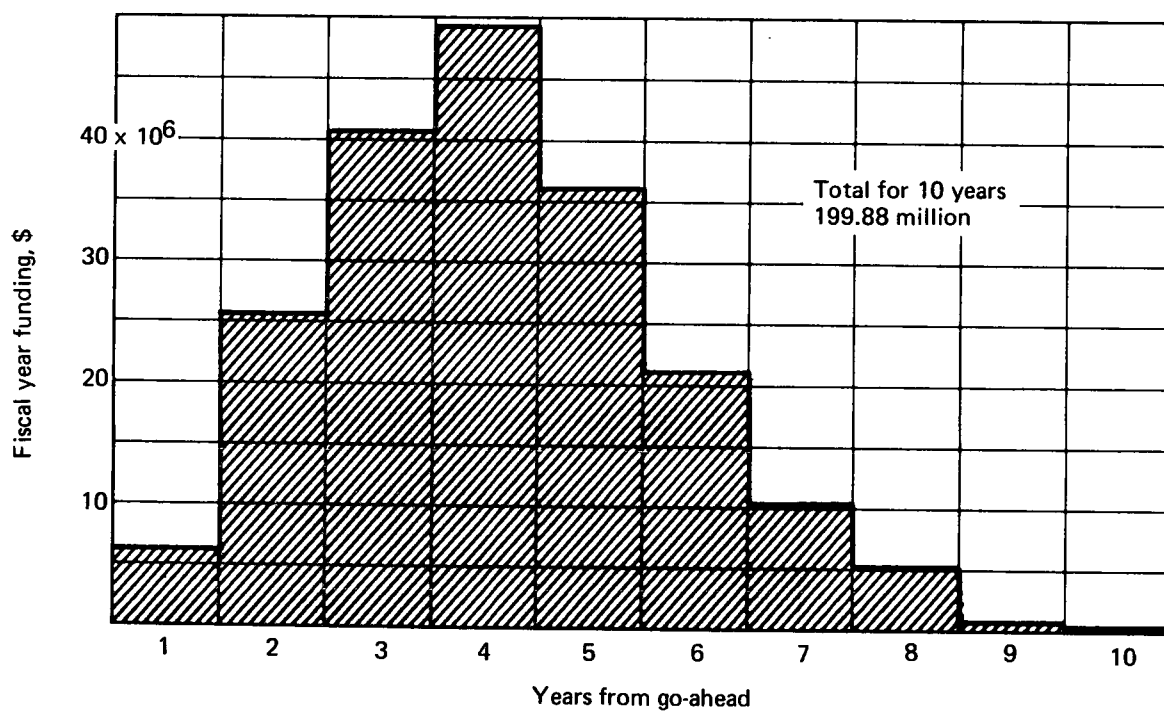


FIGURE 21.—STRUCTURES AND MATERIALS

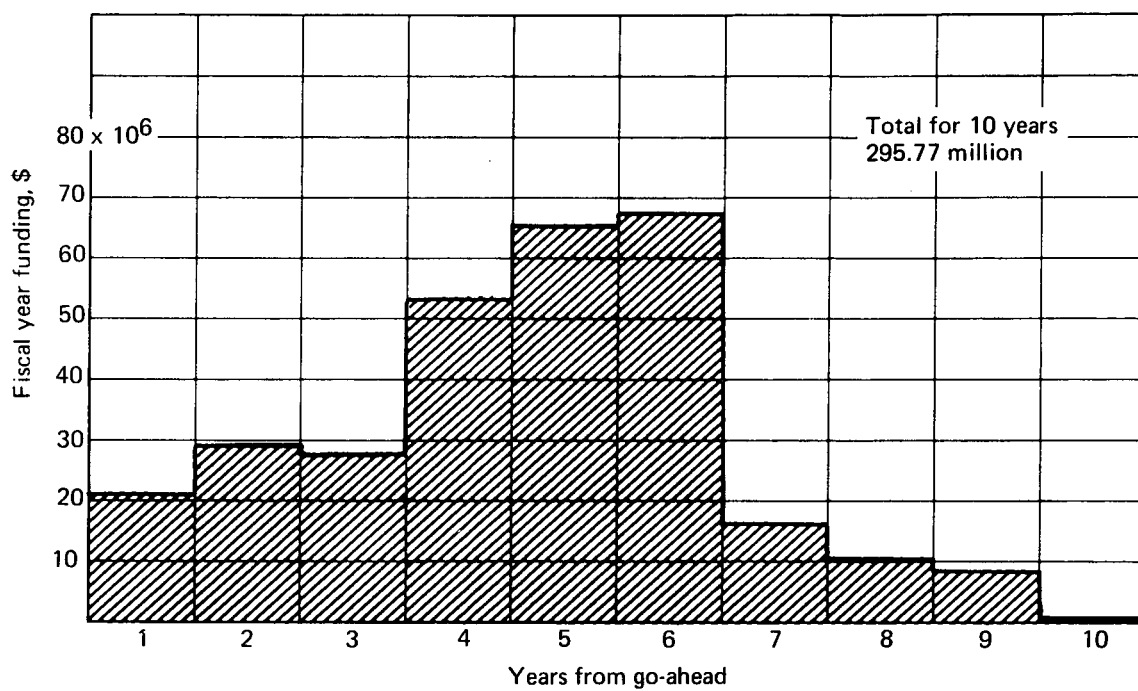


FIGURE 22.—POWER SYSTEMS

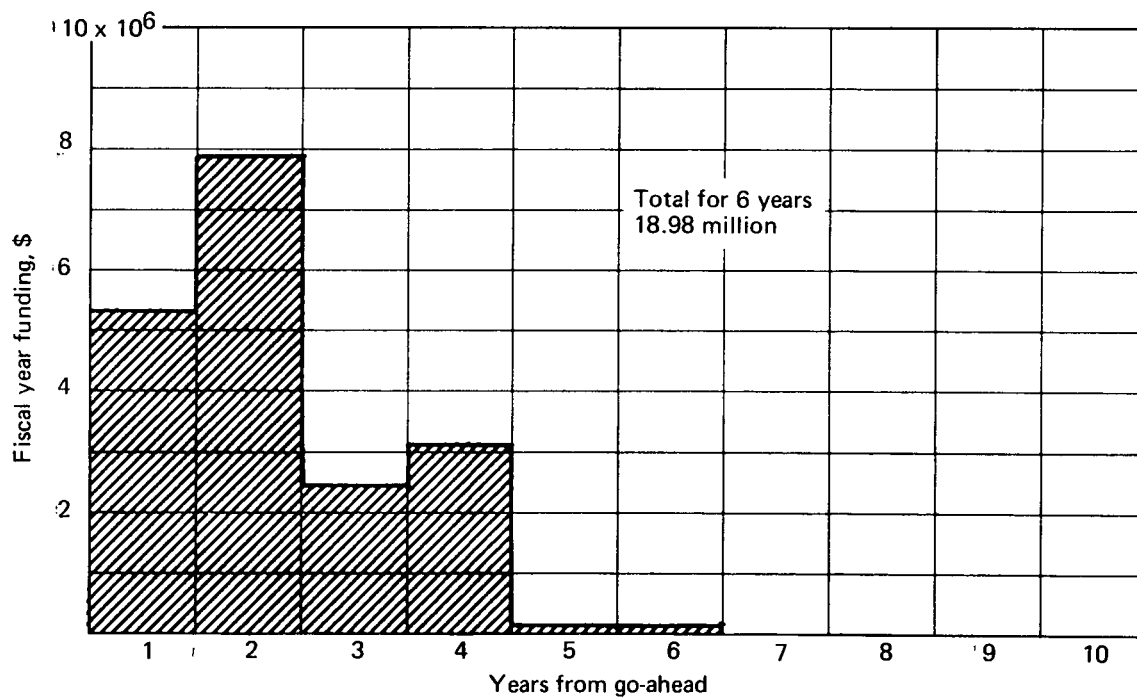


FIGURE 23.—CONTROL OF FLIGHT

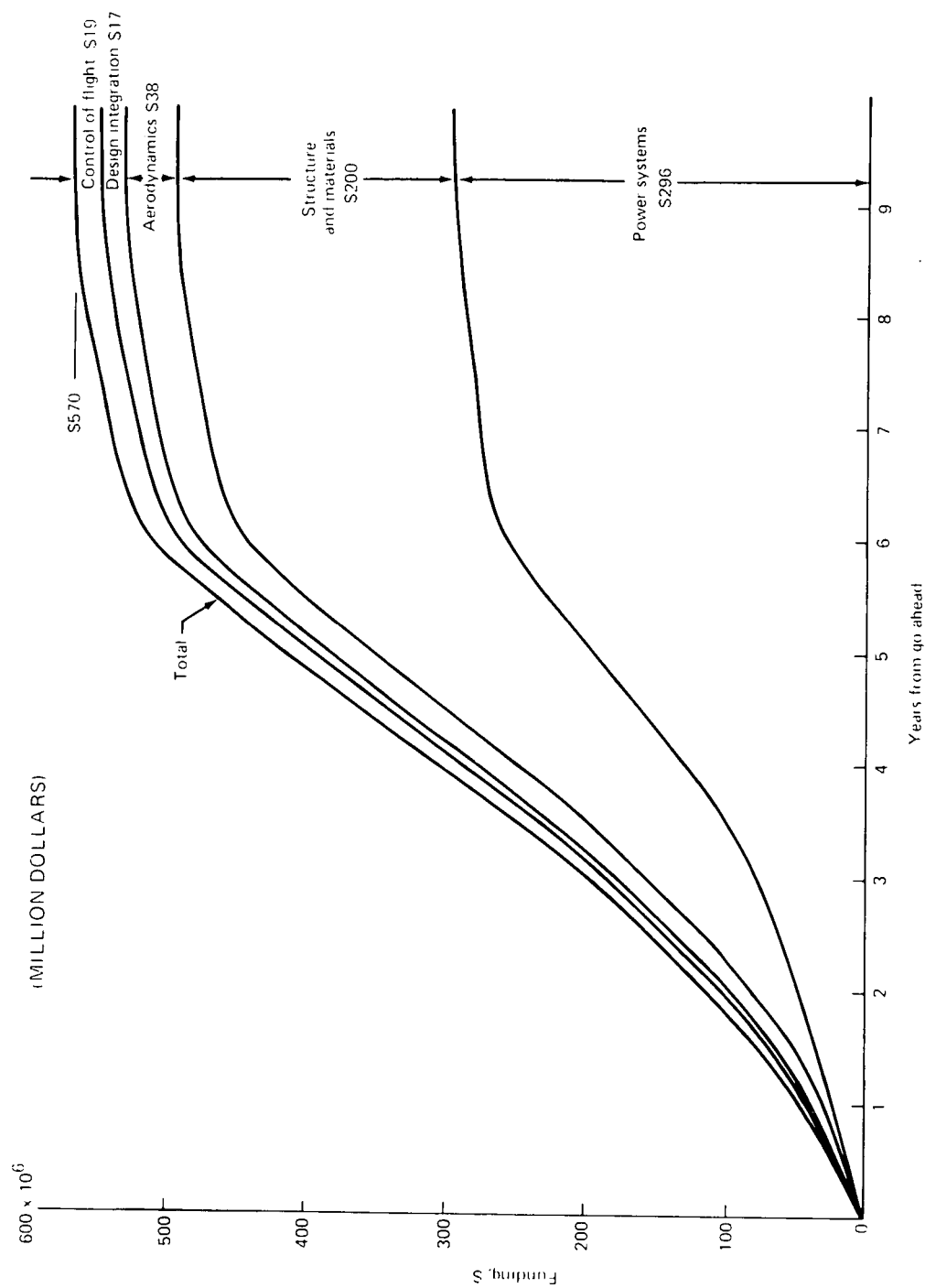


FIGURE 24.—CUMULATIVE FUNDING—TOTAL PROGRAM

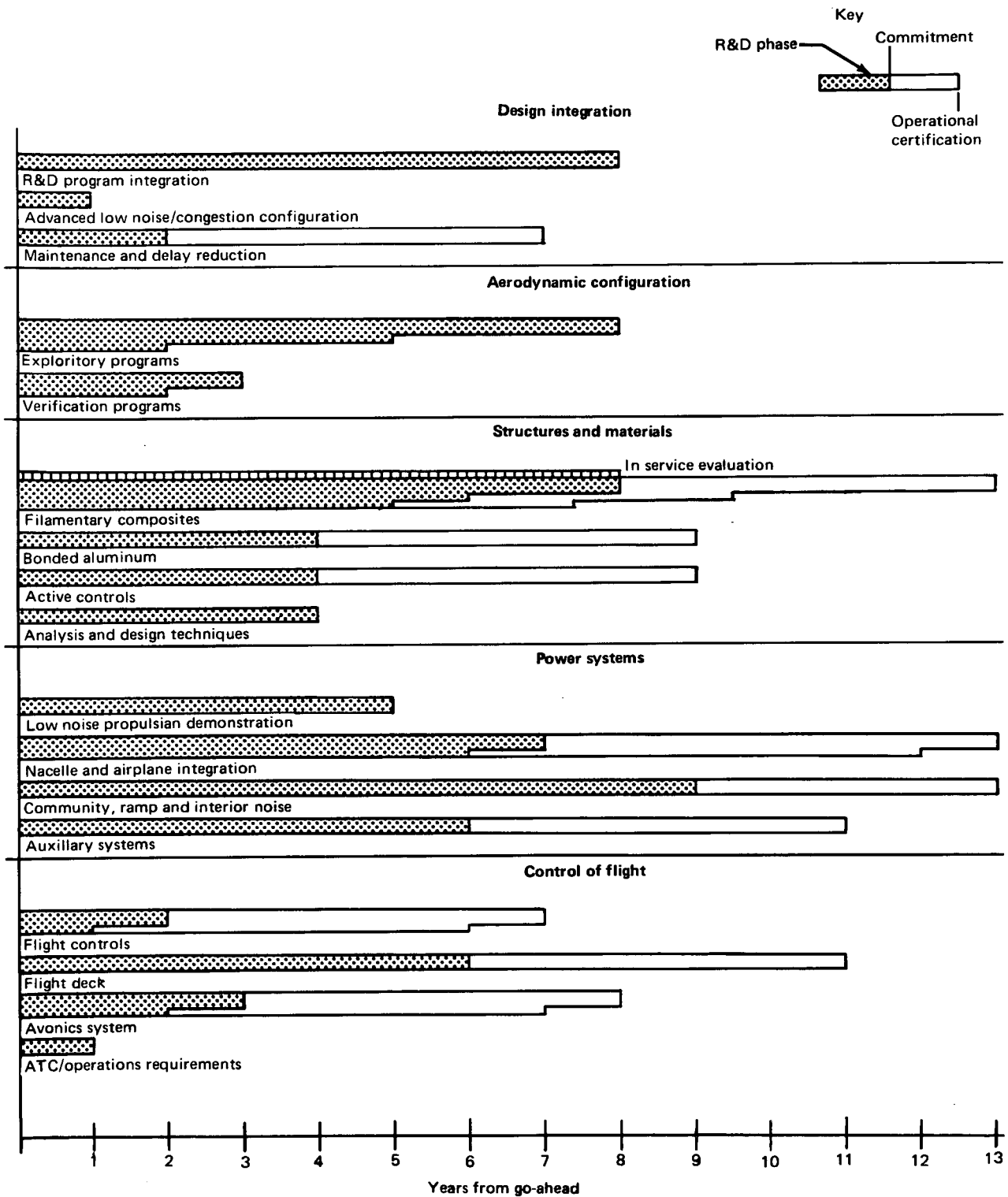


FIGURE 25.— RESEARCH AND DEVELOPMENT MAJOR ITEM SCHEDULE

PROGRAM ASSESSMENT

An assessment of the adequacy of the recommended program was made. This was accomplished using a comparison of the characteristics for potential transport configurations defined for three operational time periods. Major characteristics of these three configurations are shown by table 2. They are defined to the same Mach 0.98 cruise speed, 40,000 pound (18,140 kg) payload, and 3000 nmi (5560 km) range capability, but to the different technology levels that could be available for operational application at the three time periods. The first part of table 2 reflects the three operational dates, the configuration arrangements used for the assessment, and the consistent payload-range speed characteristics. This is followed by the estimated weight, noise level and economic potential that can be expected by application of the advanced technology characteristics noted for each technical area.

Table 2 reflects characteristics of aircraft that could be made operational in 1977, 1981, and 1985. The 1977 airplane reflects current technology except that it includes use of supercritical technology required to achieve Mach 0.98. As such it includes less sophistication than the Model -611 airplane described by table 1 which was used for advanced technology evaluation. The Model -620 airplane was used as the 1981 version and best estimates were used for the 1985 version. The change in engine location and addition of advanced technologies from the 1977 airplane to the other two examples reflects the results of both the configuration and advanced technology studies conducted during the contract. Using the 1977 airplane as the base point for comparison, the following benefit assessment for the later time period can be made.

Weight

Use of unidirectional composites and center of gravity management to permit improved lift/drag conditions results in a 10.7% reduction in takeoff gross weight for the 1981 airplane. This can be attained in spite of additional weight in the propulsion area for noise attenuation. Application of multidirectional composite structure, active controls and projected L/D and t/c improvement permits a maximum takeoff gross weight reduction of 30% for the 1985 airplane when compared to the 1977 baseline.

Economics

The cumulative effect of improvements in all technology areas is reflected in the increased Return on Investment from 15.9% to 17.7% for the 1981 airplane and from 15.9% to 20.5% for the 1985 airplane. The recommended program includes effort directed toward reduction of maintenance and delay costs. Goals established for that effort are not included in the ROI estimates shown on table 2.

Noise

Developments in the operational procedure area to permit curved decelerating approaches along with predicted improvements in attenuation effectiveness are included in the 1981 airplane data. These improvements are expected to result in a traded noise level reduction from 3.7 EPNdB to 12.1 EPNdB below current FAR Part 36. The 1985 airplane could take advantage of the complete noise reduction program recommended for the propulsion area as well

**TABLE 2.—
ADVANCED TECHNOLOGY PROGRAM ASSESSMENT
POTENTIAL CONFIGURATION EFFECTS**

CONFIGURATION SUBJECT	STATUS TECHNOLOGY AIRPLANE 3	MODEL 767-620 PHASE II CONFIGURATION STUDY	MODEL 767-XXX 1
Potential certification date	1977	1981	1985
Speed: Mach no.	0.98	0.98	0.98
Engine arrangement	3 tail mounted engines	2 wing—1 tail mounted engine	2 wing—1 tail mounted engine
Range	3000 nmi (5560 km)	3000 nmi (5560 km)	3000 nmi (5560 km)
Payload	40,000 lb (18,140 kg)	40,000 lb (18,140 kg)	40,000 lb (18,140 kg)
T. O. Gross weight	381,400 lb (173,000 kg)	340,600 lb (154,900 kg)	266,800 lb (121,000 kg)
Noise level (traded) EPNdB below current FAR part 36	-3.7	-9.6 (-12.1) 2	Not established Potential 15 - 18 2
Economics—ROI % at 1000 nmi and 0.55 LF	15.9	17.7	20.5
TECHNOLOGY Aerodynamics	Supercritical airfoils and area ruling	Supercritical airfoils and area ruling	Advanced airfoils and area rulings 6% L/D and .04 t/c improve- ment
Structures	Current aluminum baseline Flight critical stability augmentation	Unidirectional com- posites (approx. 10% weight reduct.) Plus c.g. management	Unidirectional com- posites and limited multi-directional composites + other (approx. 20% wt. red.) Plus active control system
Control of flight Operations	Unstable with c.g. control 2 segment, decelerat- ing straight in approach	Unstable with c.g. control Curved, flight idle decelerating approach; 4½ glide slope	Unstable with active control system 40 flight management
Propulsion	Current technology T/W—4.75 SFC at cruise -0.672	ATSA-4-2800-24 30% improvement in attenuation effectiveness	Not established

1 Phase II redirection did not permit
definition of this configuration

2 Including improved operational systems
and procedures

3 This configuration reflects addition of supercritical
airfoil technology and SAS to achieve Mach .98 for
current B-747, DC-10, L-1011 technology type aircraft.

as additional improvements in avionics and operational procedures. As noted previously, firm estimates of the gains that can be made in the propulsion area are not possible at this time. An estimate, however, can be made that indicates a reduction of 10 to 20 EPNdB below current FAR Part 36 for the 1985 airplane.

Emissions

Firm engine contractor data, relative to projected emission characteristics of engines applicable to either the 1981 or 1985 airplane, were not available at the completion of this study. Preliminary information, however, indicates that with the exception of nitrogen oxide, the goals established in the engine contractor Statement of Work are attainable.

The recommended program also includes investigation of a powered wheel concept, which would be effective during docking and taxi operations in the terminal area. This concept is in a very early preliminary investigation stage, and the weight and cost are not reflected in table 2. Assuming that the concept can be mechanized in an acceptable manner, a preliminary analysis indicates that it would offer an up to 60% reduction of emissions in the terminal area, probably for the 1985 airplane.

Congestion

Significant gains can be made toward reducing terminal and airway congestion by successful completion of the recommended airborne avionics programs. It is pointed out that full advantage of these programs can be realized only if related developments are pursued in parallel for the supporting ground control provisions.

In summary, the program assessment revealed that major breakthroughs are possible if the necessary research and development programs are properly supported. The attainable breakthroughs could be accomplished within the 1975-1985 time period covered by this study. The realities of foreign competition suggest a sense of urgency in implementing a comprehensive research and development program.

PROGRAM PRIORITIES

The Recommended Action section of this volume contains approximately 50 individual program items for which specific action is recommended. The contractor considers all of the items to be important toward meeting ultimate objectives. However, some of the individual items may deserve a greater degree of emphasis as a function of their expected payoff, level of risk, or desire to emphasize one of the major goals identified by the CARD policy study. Table 3 provides a list of primary program items, for each of five technology areas, that the contractor considers to be most important because of high risk or payoff potential. These are listed for each of three major goals: reduced noise and emissions; reduced congestion; and international competition and reduced cost.

The table reflects 16 of the approximately 50 items included in the total program. Use of 16, rather than all of the items included in the program, permits concentration on those that deserve the greatest emphasis. It can be noted that the listing for each technology area

TABLE 3.—KEY PROGRAM ITEM PRIORITY FOR MAJOR GOAL ATTAINMENT

Technical area	Major goal	Reduced Noise/emissions	Reduced congestion	International competition & reduced cost
Aerodynamics		<ol style="list-style-type: none"> 1. Novel concepts 2. High crit. M cowls 3. Adv. airfoils 	<ol style="list-style-type: none"> 1. Novel concepts 	<ol style="list-style-type: none"> 1. Novel concepts 2. High crit. M cowls
Structures & materials		<ol style="list-style-type: none"> 1. Advance composites 		<ol style="list-style-type: none"> 1. Bonded al. str. 2. Adv. composites 3. Integ. act. cont. sys.
Design integration		<ol style="list-style-type: none"> 1. Low noise/congestion config. 2. R&D prog. integ. 	<ol style="list-style-type: none"> 1. Low noise/congestion config. 2. R&D prog. integ. 	<ol style="list-style-type: none"> 1. R&D program integ. 2. Maintenance and delay reduction.
Power systems		<ol style="list-style-type: none"> 1. Prop. sys. demo 2. Comm. ramp & int. noise 3. Powered wheel 	<ol style="list-style-type: none"> 1. Adv. aux. sys. 	<ol style="list-style-type: none"> 1. Prop. sys. demo 2. Adv. aux. sys.
Control of flight		<ol style="list-style-type: none"> 1. ATC/operations 2. Adv. nav. sys. dev. 3. Adv. flt. deck dev. 	<ol style="list-style-type: none"> 1. ATC/operations 2. Adv. nav. sys. dev. 3. Adv. flt. deck dev. 	<ol style="list-style-type: none"> 1. Application of CCV philosophy 2. Appl. of load allev. cont. to config. opt. 3. ATC/operations

varies depending on the goal that is considered. In a like manner, the priority for a technology item varies dependent of the goal that is considered.

A qualitative evaluation of priority among the five technology areas for each major goal is provided below:

- For the reduced noise and emissions goal, the Power Systems and Control of Flight items should receive highest priority for early results. The novel design concept and low noise/congestion configuration efforts are important over the long term.
- In the case of reduced congestion, the Control of Flight items assume greatest importance for both the short and the long term. Again, the novel design concepts and low noise/congestion configurations assume importance for the long term.
- When the goal of ensuring a competitive international position and minimum cost is considered, priority among the five technology areas becomes more difficult. Airplane cost reduction should emphasize structures and materials, aerodynamics, power systems and control of flight items in approximately that order.
- A well-planned and executed R&D program is important to the accomplishment of each goal. This is indicated by the R&D program integration entry.

RECOMMENDED ACTIONS

INTRODUCTION

This section contains descriptions of individual research and development program items that, in the opinion of the Contractor, are required to bring the state-of-readiness of applicable advanced technologies to the point that they could be committed to future commercial transport programs. The program items are described under technology headings as follows:

- Design Integration
- Aerodynamic Configuration
- Structures and Materials
- Power Systems
- Control of Flight

In addition, the need for equipment and facilities to support the research and development program and a description of potential demonstration vehicles are provided under the heading Equipment and Facilities and Conceptual Approach. An overview of the total program reflecting the collective payoff potential, cost, and schedule impact of the individual programs is contained in the previous Integrated Program section.

The program items described in this section resulted from the studies described in Volume I, which included evaluation of the payoff offered by application of discrete advanced technology candidate items to a potential future commercial transport configuration. Those that showed promising potential were selected to be included in the volume.

Each individual program item is covered from the following standpoints:

- **Payoff Potential**
Quantitative values are provided relative to the economic, performance, weight or other parameter benefits that can be expected for many of the items. For others, a qualitative description of potential benefits is provided.
- **State-of-Readiness**
An evaluation of the status of development as known by the Contractor, and a description of the deficiencies that exist are provided.
- **Recommended Action**
Needed analysis, design, laboratory test and/or demonstration tests required to bring the state-of-readiness to commitment status is described. This includes the type of organization, i.e., industry, government agency, or academic, that should be involved.

- **Cost and Schedule**
Estimates of the funding required to pursue the recommended action and the appropriate schedule that should apply, are included.

Unless otherwise stated, the funding estimates are based on a single industry, academic or government agency being involved in each recommended program item. For ease of reference, a summary of the estimated funding for several program items is shown by table 4. The funding estimates were developed using Contractor historical information applied to the level of program definition permitted by the contract budget. Firm funding estimates will require more detail definition, however, a reasonable degree of confidence can be applied to the values shown.

DESIGN INTEGRATION

In the same manner that this study contract involved the integration of multiple technical disciplines, there is need for similar effort in the future. The recommended research and development program itself, will involve the efforts of many government, industry and research organizations. Further advancements and potential payoff are offered by pursuit of overall configurations that include the investigation of unconventional approaches to aircraft noise and operational congestion. In addition, an attractive economic payoff is potentially available if historic problems that have affected airline maintenance and delay records, are isolated and corrected in future design.

All or several of the technical disciplines involved in the research and development needed to support future aircraft design are affected by the above needs. Programs that need an integrated approach are listed on figure 26, and are described in this section.

R&D Program Integration

Potential Payoff

Integration of the efforts of the several industrial research and development programs described in this report is required to ensure efficient application of funding and a productive output. The objectives of the integration effort would be:

- Development and continual update of the requirements to which the research and development effort is devoted.
- Definition of the interface between the various programs and the organizations involved.
- Identification of voids in the program and definition of the action required.
- Assessment of the adequacy and applicability of the individual and collective developments as reflected in overall configurations designed to specific goals.

TABLE 4.—R&D FUNDING
(Millions of dollars)

	1	2	3	4	5	6	7	8	9	10	Total
Design integration											
Configurations											
Low noise/congestion configuration	1.75										1.75
R&D configuration integration	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0			10.0
Maintenance and delay reduction	0.1	1.5									1.6
Subtotal	3.85	3.5	2.0	2.0	2.0	2.0	1.0	1.0			17.35
Aerodynamic configuration											
Exploratory programs											
Advanced Airfoils	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2			9.6
High critical mach cowls	0.8	0.7									1.5
Subsonic/transonic area ruling	0.5	0.7									1.2
Analytical methods improved design and analysis tools	0.6	0.6	0.6	0.3	0.3						2.4
Novel design concepts	2.4	3.6	2.4	3.6	2.4	3.6					18.0
Verification programs											
"Interference free" transonic test section	1.2	0.4	1.0								2.6
Flight/wind tunnel correlation	1.2	0.6									1.8
Roughness and excrescence drag	0.2	0.4									0.6
Sonic boom during cruise	0.4	0.1									0.5
Slightly below Mach 1.0											
Subtotal	8.5	8.3	5.2	5.1	3.9	4.8	1.2	1.2			38.2
Structures and materials											
Materials processes											
Advanced filamentary composite structure	4.15	13.92	30.56	43.94	37.24	22.29	10.12	5.02	0.92	0.33	168.49
Bonded aluminum structure	0.8	8.2	6.9	3.0							18.9
Improved corrosion protection	0.08	0.01									0.09
Titanium structure	—										
Improved steel structure	—										
Load alleviation											
Integrated active control system	1.90	2.0	2.73	1.25							6.9
Improved analysis and design capability	2.0	2.0	1.0	.50							5.5
Subtotal	7.93	26.13	41.21	48.69	37.24	22.29	10.12	5.02	0.92	0.33	199.88

TABLE 4.—R&D FUNDING(Continued)

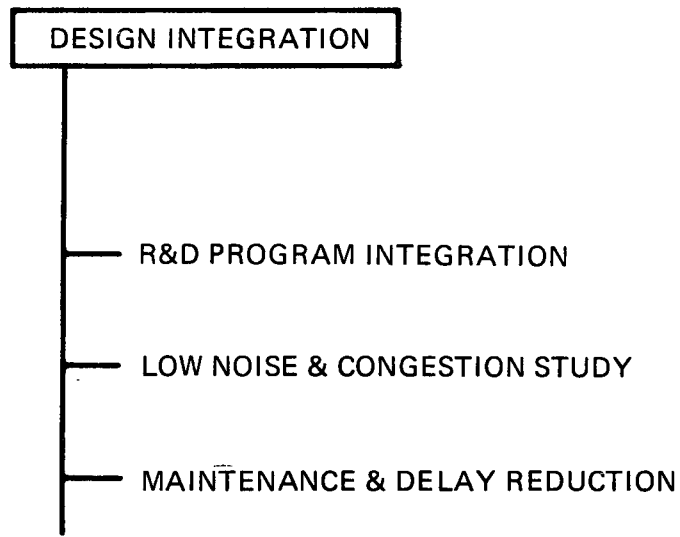


FIGURE 26.—DESIGN INTEGRATION PROGRAMS

This work would assure that the proper effort is applied in the proper areas and to consistent requirements, for minimum cost and schedule.

State-of-Readiness

A comprehensive research and development program needed to bring the state-of-readiness of all technologies to a commitment status, has been defined. That program is defined in this report, and provides the planning base to proceed with the necessary action. In the same manner that the basic program was defined on an integrated basis, this program should be pursued with a continuous overview activity directed toward fulfilling the objectives described above.

Recommended Action

It is recommended that a contract be issued to the airframe industry, on a continuing basis throughout the development period. This would be similar to this contract, with possible expansion to cover the total future air transportation system. The Contractor would act in an advisory capacity to the NASA.

Cost and Schedule

It is recommended that a Contractor be funded at a level of \$2,000,000 per year over the program period to meet the objectives noted above. Additional funding would be required if the effort were expanded to a total air transportation system integration effort. A summary of funding and schedule is shown on figure 27.

Advanced Low Noise/Congestion Configuration Study

Objectives and Payoff

The growing importance of environmental considerations and traffic congestion requires complete exploration of every potential method for minimizing noise and terminal area traffic congestion by intelligent configuration design and operational planning of future aircraft. The objectives and payoff of this design integration effort would be:

- Definition of airplane performance requirements that would ensure low aircraft noise and reduce traffic congestion.
- Definition of aircraft design features that contribute to the achievement of these airplane performance requirements.
- Integration of these features into a variety of configuration concepts, both unconventional and conventional types.
- Evaluation of these designs to identify the most promising concepts.
- Complete evaluation of the more promising concepts to establish design details, risks and economics.

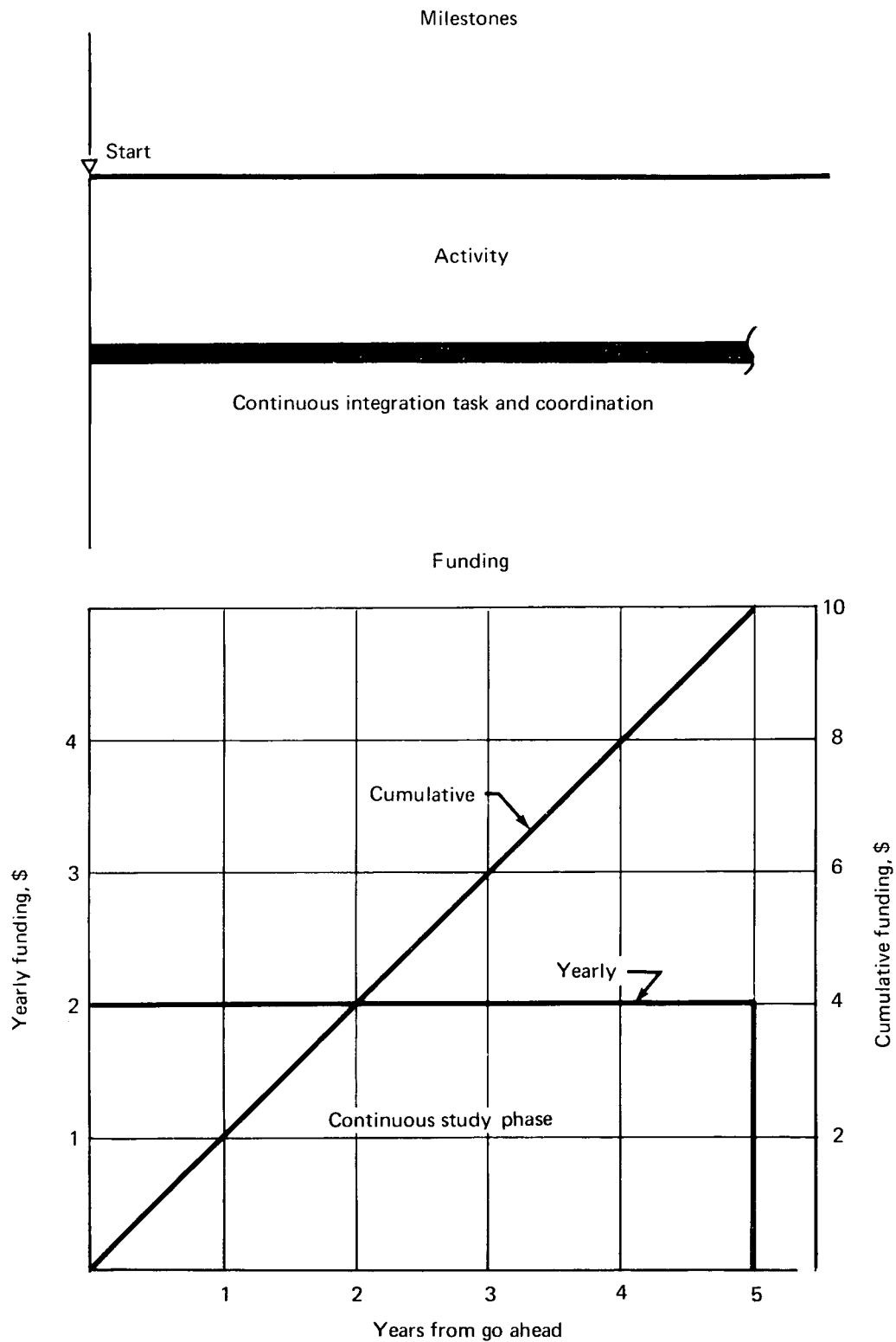


FIGURE 27.—R&D PROGRAM INTEGRATION FUNDING SCHEDULE

- Identification of high risk areas and technical deficiencies with recommended action.

State-of-Readiness

The basic technical knowledge to complete this study exists and identification of several promising concepts has been made. High priority national goals for reduced airplane noise and air traffic congestion have been identified in the CARD study. An integrated design program is required for application of the existing technical capability toward achievement of these national goals.

Recommended Action

It is recommended that a one year, three phase study contract be issued to an industry contractor. The first phase of this study would be a two months period used to identify unconventional airplane performance and design factors that are beneficial in reducing noise and traffic congestion. The second phase of the study would be used to establish configurations that incorporate the results of the first phase. Alternate approaches to configurations would be used to provide a broad base for the study. This second phase would require four months and would produce the final configurations chosen for phase three. The third phase of the study would require six months and be used to evaluate thoroughly the most promising configuration candidates from phase two. The analysis would be in sufficient detail to establish reasonable confidence as to practicality, performance, cost, operating economics and safety.

Cost and Schedules

It is recommended that funding of \$1,750,000 for a one year study effort be provided. See figure 28 for a summary on funding and schedule.

Maintenance and Delay Reduction

Potential Payoff

Maintenance costs and delay-causing problems constitute major airline considerations since they directly affect potential profit. Identification and analysis of those airplane systems, components, and practices which have been major contributors to in-service problems should be accomplished. Such a program would provide a firm foundation for directing emphasis toward those areas or items of highest potential for improvement on future airplanes. Considering maintenance, only, the sensitivity of in-service maintenance costs over the life of the study airplane is shown by figure 29. This indicates that a reduction of two man hours direct maintenance per flight hour, or a \$20 per flight hour reduction in cost of direct maintenance material are shown to be nearly equivalent in value to a 2% reduction in airplane drag or specific fuel consumption. The objective and expected payoff from research effort in this area is to provide the basis for realization of savings of such magnitude. Potential reduction in delay costs would be an added benefit.

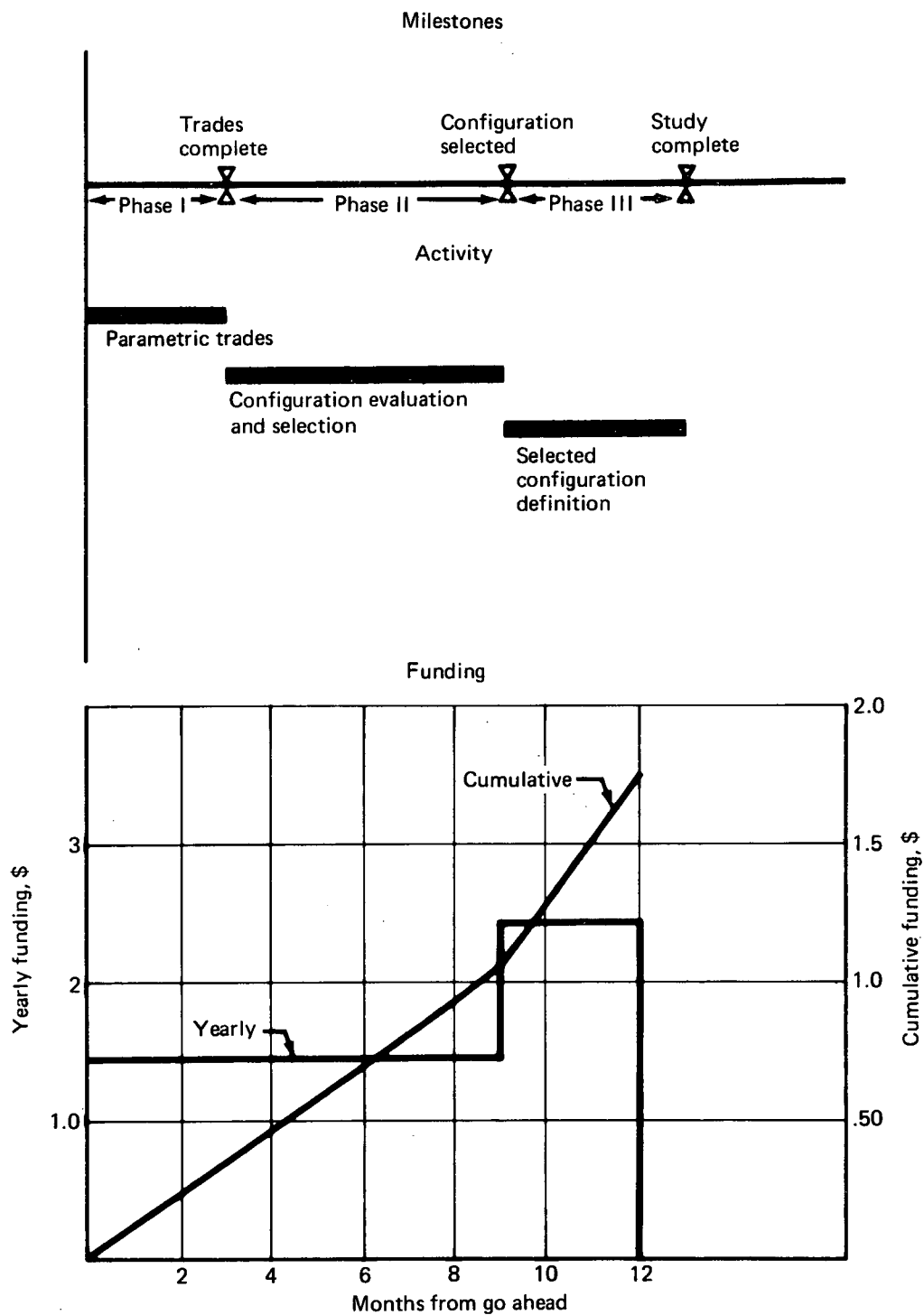


FIGURE 28.—LOW NOISE AND CONGESTION STUDY FUNDING SCHEDULE

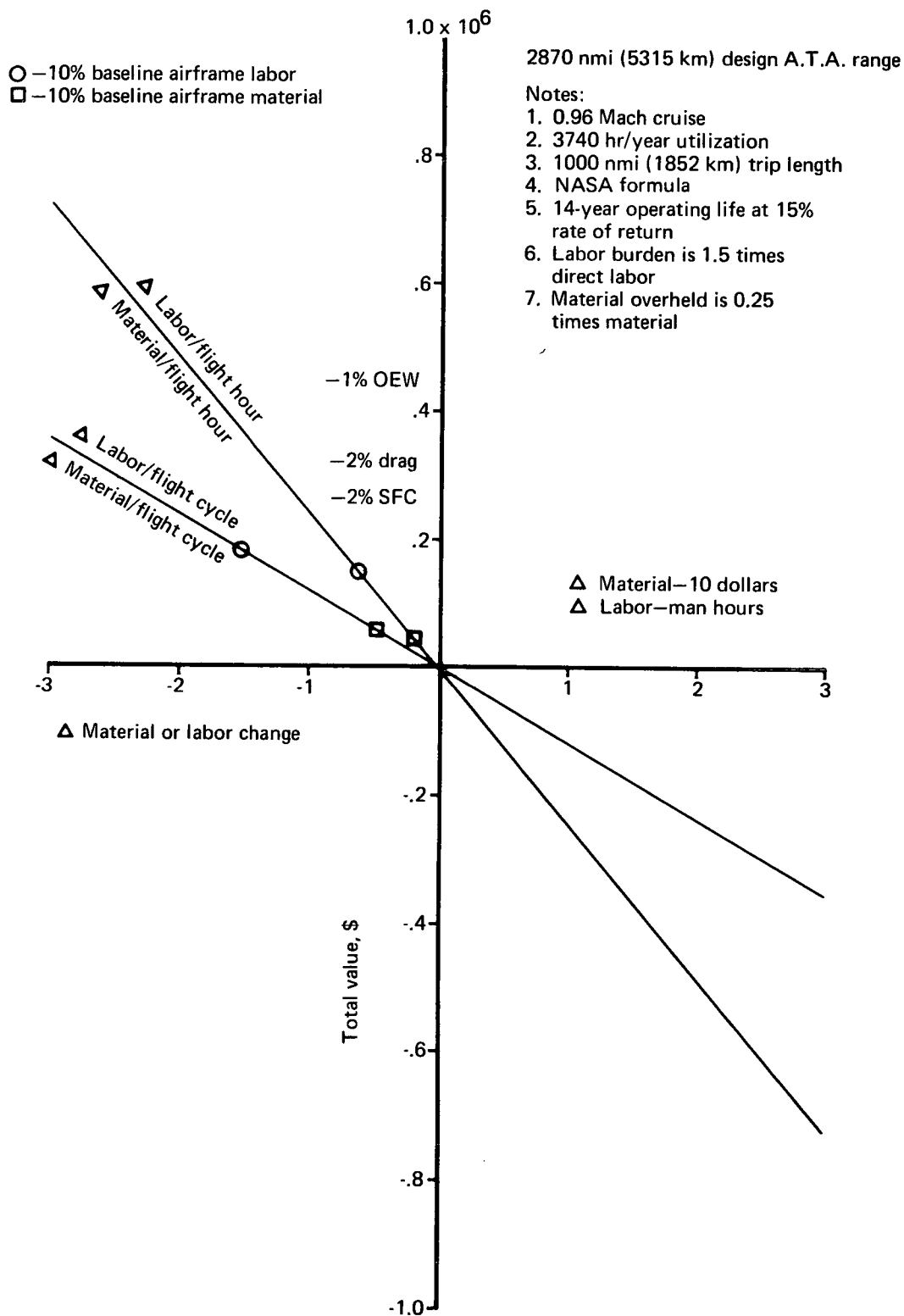


FIGURE 29.— TOTAL VALUE OF MAINTENANCE

State-of-Readiness

Analysis of historical data has been accomplished to identify the major contributors in in-service problems as a function of airplane models, ATA systems, and the measurement parameters shown by figure 30. The consistent relationship, model to model, clearly indicates the "top ten" system items that have constituted the major problem areas. This preliminary analysis provides the base for more detailed analyses to isolate the specific causes of past problems. These results can then be used to provide guidelines for future programs and to conduct specific investigations toward defining means to eliminate problems and minimize major in-service maintenance on future aircraft.

Recommended Action

A two-phase program to be conducted by airplane manufacturers in cooperation with airline operators is recommended as follows:

Phase I

During this phase a detailed review and analysis would be made of past airplane mechanical interruption summaries, statistical monitoring reports, nonroutine maintenance reports, ranking reports, field service reports, and service bulletin data on the top ten problem contributor aircraft systems. Results would be contained in manuals applicable to each aircraft system illustrating design features that have contributed to both good and poor service experience in a form usable by technical management and/or design engineers. Major problem areas would be identified and described for more detailed evaluation during Phase II.

Phase II

Based on the Phase I analysis, the Phase II effort would be devoted to the investigation of design methods to overcome major deficiencies of past hardware design approaches that contributed to major problems, including material costs. The output would be recommended methods, procedures or design features for those problems, presented in design guide document form for use on future programs.

Cost and Schedule

A funding level of \$90,000 over a one year period is recommended for the Phase I effort. Participation by more than one airplane manufacturer and airline would result in additional costs. Firm Phase II planning including cost and schedule would result from the Phase I analysis. A preliminary estimate for the Phase II effort is \$1.5 million over an 18 month period. This is shown graphically by figure 31.

AERODYNAMIC CONFIGURATION

The sensitivity of airplane performance and operational costs to improvements in aerodynamic efficiency has been well demonstrated for both low speed and high-speed flight. More recently airplane noise has become an important design requirement. In this respect, also,

ATA system category																													
Cost category	Model	00 General	21 Air conditioning	23 Communications	24 Electrical power	25 Equipment/furnishings	27 Flight controls	28 Fuel	29 Hydraulic power	31 Instruments	32 Landing gear	33 Lights	34 Navigation	36 Pneumatics	38 Water and waste	49 APU	51 Structure, general	52 Doors	53 Fuselage	55 Stabilizer	56 Windows	57 Wings	71 Power plant, general	72 Engines	73 Engine fuel	75 Engine air	77 Engine indicating	78 Exhaust	80 Starting
Maintenance costs	747 720 727-100 707-320	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	
Delays	707-300 737-200 727 747	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	
In-service changes	737 727 747	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	
Nonroutine maintenance actions	720 737 727 747	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	
Top ten		21	25	27	29	32	34										52					57		72				78	

FIGURE 30.—TOP TEN MATRIX

FIGURE 30.—TOP TEN MATRIX

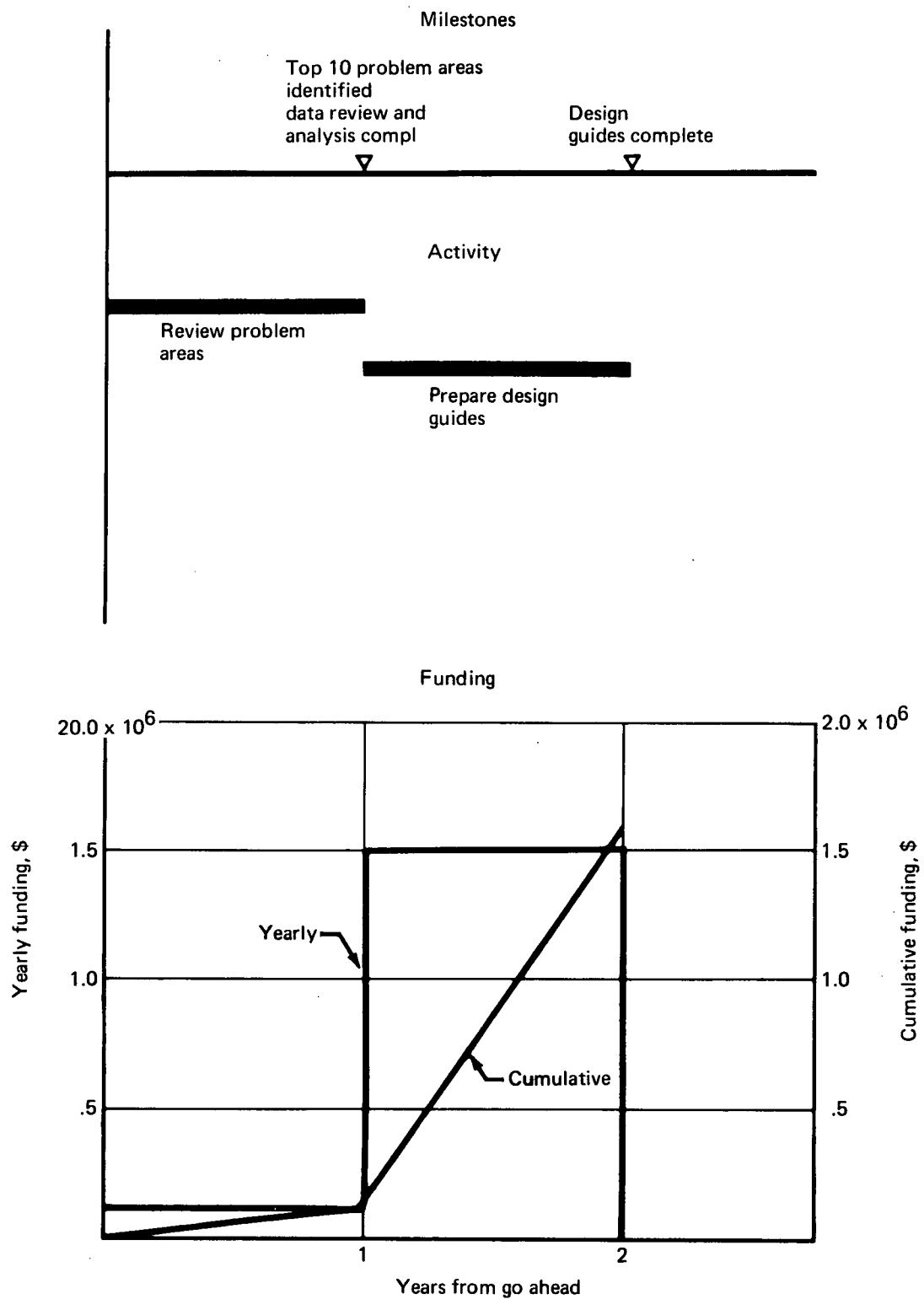


FIGURE 31.—MAINTENANCE AND DELAY REDUCTION FUNDING SCHEDULE

aerodynamic efficiency plays a significant role since the noise generated by an airplane during takeoff and landing approach is a function of required engine thrust, which in turn is directly related to aerodynamic lift-to-drag ratio. Thus, it is clear that improvements in aerodynamic efficiency must be exploited to their fullest in any new commercial airplane program.

Recent development of the supercritical airfoil has demonstrated that the limit in airfoil design has not been reached. Research and development work on airfoil design should be continued if further improvements are to be achieved. The extension of supercritical technology to engine inlet, cowl design, and fan turbo-machinery blades is also promising and should be pursued.

The benefits of area-ruling for transonic and supersonic flight have been developed sporadically since the early nineteen-fifties. Recently the value of refined area ruling has been demonstrated in the wind tunnel for the NASA High Performance configuration. A systematic theoretical and test program should be undertaken to provide basic understanding of the mechanism involved in these and other refined area ruling concepts, so they can be applied with assurance to other wing planforms and airplane configurations.

Aerodynamic prediction methods, both theoretical tools and test facilities must be improved to reduce the risk in future programs. In the past, errors in predicting aerodynamic efficiency have often been compensated for by increasing airplane gross weight and engine size. This would have serious impact in the future with the requirement for low noise levels, since noise would increase in relation to added thrust.

Many novel configuration concepts have been proposed which promise improved aerodynamic, structural, or propulsive efficiency. Accurate, detailed aerodynamic evaluation of these configurations is usually a key to confirming overall improvement. Wind tunnel test programs and detailed theoretical studies, where possible, should be undertaken to evaluate novel configurations which show promise based on initial study and evaluation.

Aerodynamic programs which should be carried out to aid in the development of advanced commercial airplanes are listed in figure 32. The individual programs are described in the following sections. These programs fall roughly into two categories: (a) exploratory and (b) verification. Expenditures for this work would amount to approximately \$8.5 million in the first year. This level of funding would be typical for the following years through completion of each program. It should be emphasized that these programs are directed toward developments in the next generation of conventional medium-to-long range commercial airplanes. Technology development requirements of other types of aircraft, such as STOL and supersonic transports, have not been considered.

Advanced Airfoils

Potential Payoff

The objective of the advanced airfoil program is to develop families of airfoils with improved section characteristics for subsonic/transonic application. An improvement of 0.05 in critical Mach number over current supercritical technology airfoils by 1980 is considered a worthwhile goal.

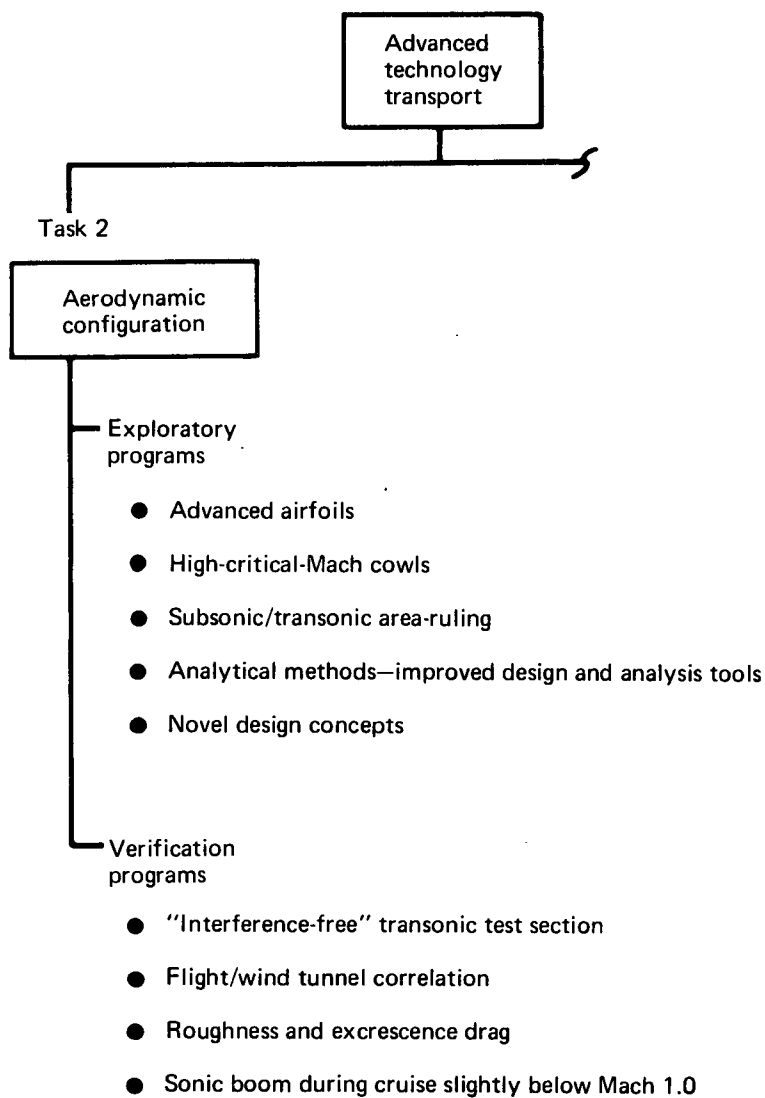


FIGURE 32.—ADVANCED TECHNOLOGY ITEMS

The potential payoff is illustrated in figure 33 where the normalized direct operating cost (D.O.C.) is plotted versus design cruise Mach number for various levels of airfoil technology. Improvement in airfoil performance would allow increased speed at the same D.O.C. or lower D.O.C. through reduced wing weight at the same speed. Achieving the 1980 goal would permit a 3% D.O.C. improvement at current cruise speeds or reduce the penalty for near sonic operation to 3%, approximately half of today's penalty.

State-of-Readiness

Progress in airfoil performance with time is illustrated in figure 34. Through the 1950's most airfoils used in airplane designs were adaptations of the NASA-developed series. For the early jet transports, modifications of these sections were applied. Increased speed requirements in the 1960's initiated an extensive airfoil design effort which led to the development of the supercritical airfoil. A significant improvement in performance was obtained—up to 0.10 in Mach number capability relative to the early NACA sections. Research and development work on airfoil design must be continued if further improvements are to be achieved.

Recommended Action

The recommended program consists of two parallel activities: (a) improve theoretical methods and (b) design and test a new family of airfoils using present semi-empirical methods and available theoretical tools. Some work is underway in both areas. This work should be continued and expanded. New theoretical methods should lead to greatly increased design capability and understanding of transonic flow phenomena. Experimental evaluation will require more and more emphasis on obtaining valid data in a two-dimensional environment in which increasingly important effects of viscosity and Reynolds number may prevail. As part of the design of a new family of advanced airfoils, the following subjects need further investigation:

- the concept of blunt trailing edges and means of reducing the associated base drag.
- variations in leading edge curvature distributions
- thickness and lift variations
- BLC applications
- scale effects
- variable geometry concepts to improve off-design operation
- conditions leading to flow breakdown and separation

Cost and Schedule

It is recommended that the airfoil development activity be pursued by NASA and industry groups to ensure a broad range of viewpoints and solutions. The suggested funding of 1.2 million per year includes three participants. This funding would provide for the testing of approximately 36 different airfoils per year. The recommended program for advanced airfoil development is summarized in figure 35.

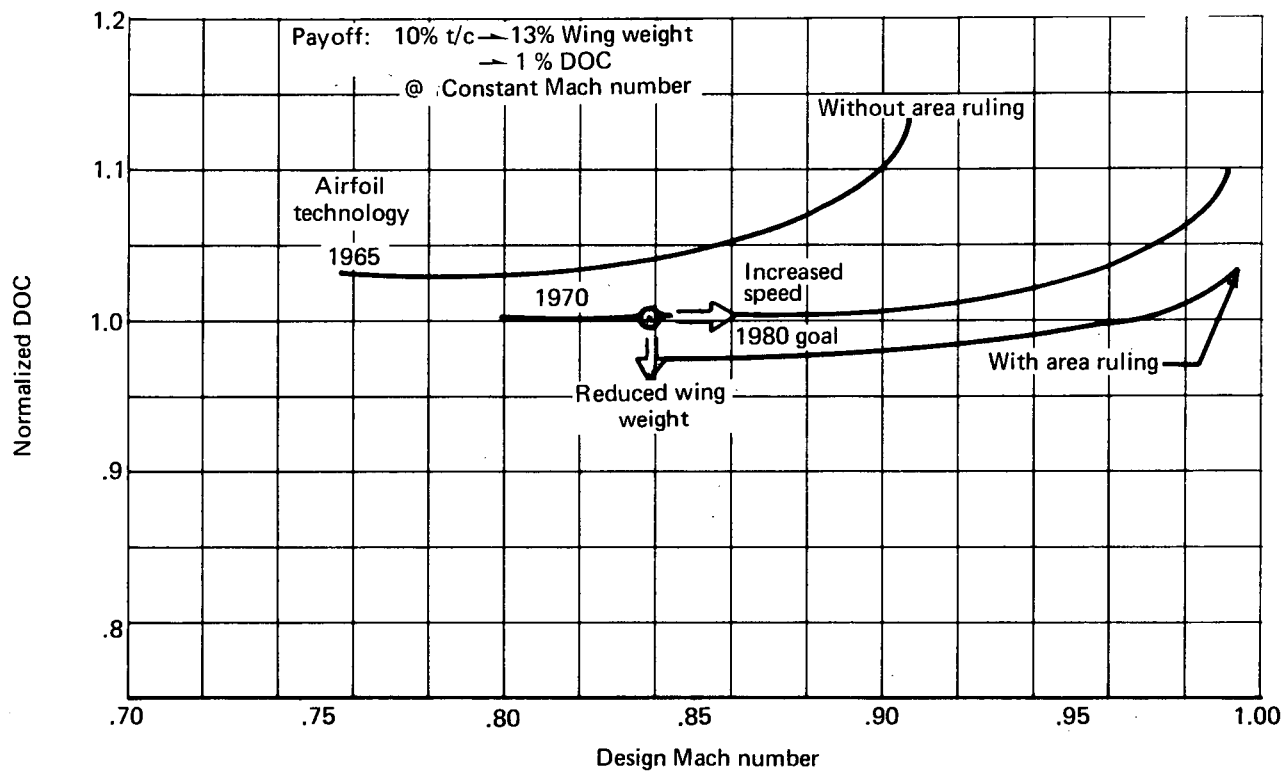


FIGURE 33.— AIRFOIL TECHNOLOGY, PAYLOAD AND RANGE CONSTANT

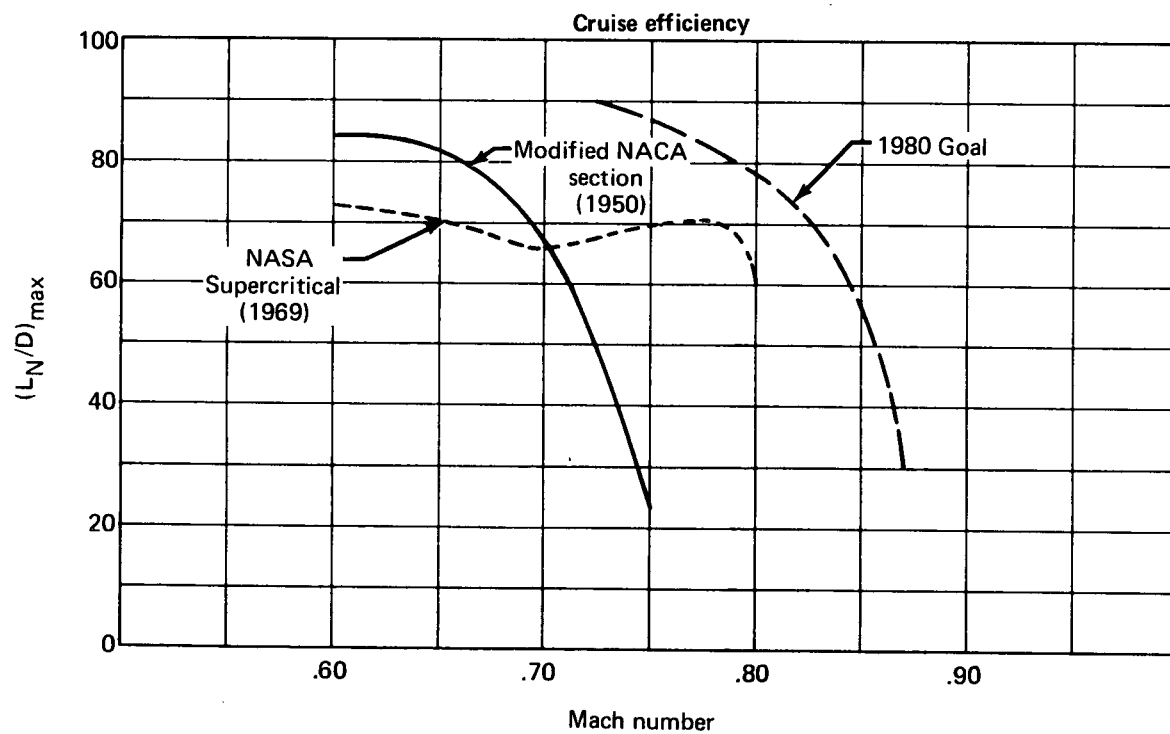
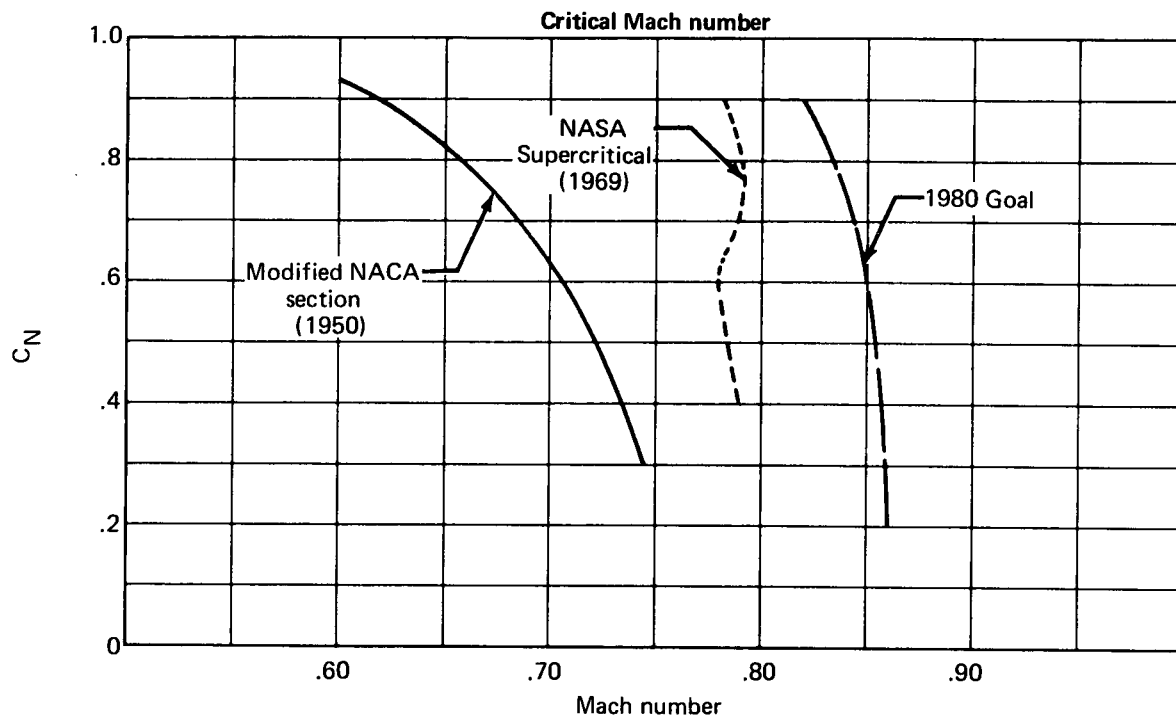


FIGURE 34.—AIRFOIL TECHNOLOGY $t/c=10\%$

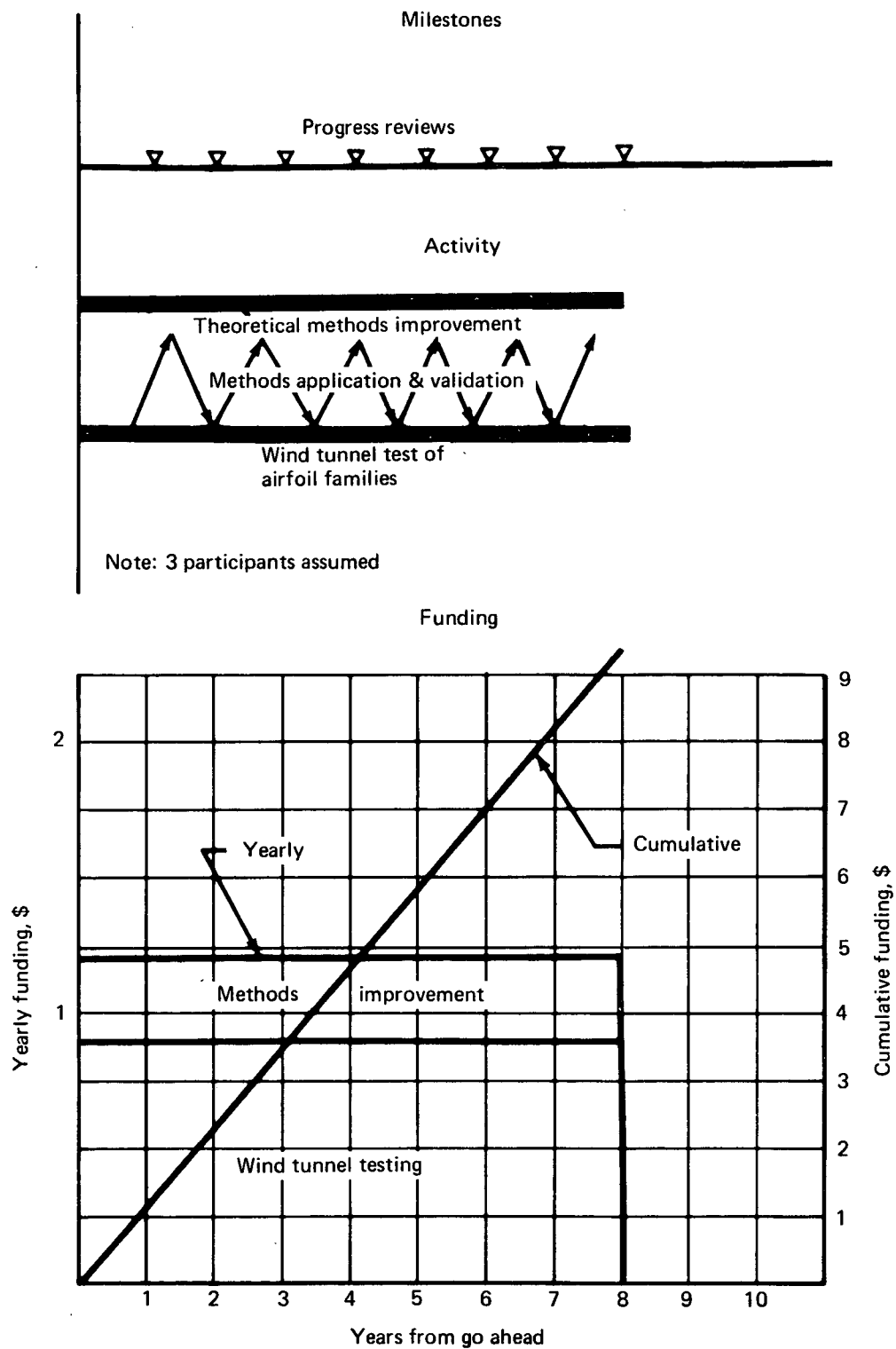


FIGURE 35.—ADVANCE AIRFOIL DEVELOPMENT FUNDING SCHEDULE

High-Critical-Mach Cows

Potential Payoff

The objective of the high-critical-Mach number cowl program is to apply supercritical technology to nacelle design to permit thick-lip inlets and lower fineness ratio cowl with improved aerodynamic, structural and acoustical properties. Application of supercritical technology involves the development of design constraints and the actual design and testing of a number of thick-lip cowl, both isolated and integrated, into a representative configuration.

The payoff could provide a noise reduction of 3 to 5 EPNdB and a weight reduction of 1000 lb per airplane on a near-sonic transport. Furthermore, an early resolution of lip thickness and cowl fineness ratio requirements will influence the design of the entire power system for a transonic transport.

State-of-Readiness

Drag rise characteristics of current technology nacelles are illustrated in figure 36. These four cowl were investigated in the wind tunnel to select a geometry for integration into the near-sonic transport. Variables included geometric fineness ratio, position of maximum diameter and inlet lip thickness. As shown, a fineness ratio 2.7 cowl with a thin-lip inlet was required to achieve an isolated drag-rise Mach number of 0.98. This compares with the JT9/CF6 thick-lip cowl which have fineness ratios between about 1.15 and 1.5.

The thin lip inlet has static and low-speed pressure recovery problems, as illustrated in figure 37, where fan-face recovery is plotted versus weight flow for various inlet lip thicknesses. At takeoff power, the thin-lip inlet experiences over 20% pressure loss compared to 3% for the thick-lip cowl. This necessitates the use of auxiliary devices, such as blow-in doors, to provide additional airflow.

Application of supercritical technology should allow the design of thicker-lip inlets for high speed, which will avoid the need for low-speed auxiliary devices and their associated weight and noise penalties.

Analytical methods for use in subsonic and transonic inlet analysis are being developed by the NASA (both in-house and under contract) and several aerospace companies. Generally speaking, however, the usefulness of these methods in the design mode has not been demonstrated, and the design constraints which must be imposed on thick-lip transonic cowl have not been developed.

Recommended Action

Similar to the advanced airfoil program, two parallel activities are recommended:

- Improve the theoretical methods.
- Design and test a series of supercritical cowl.

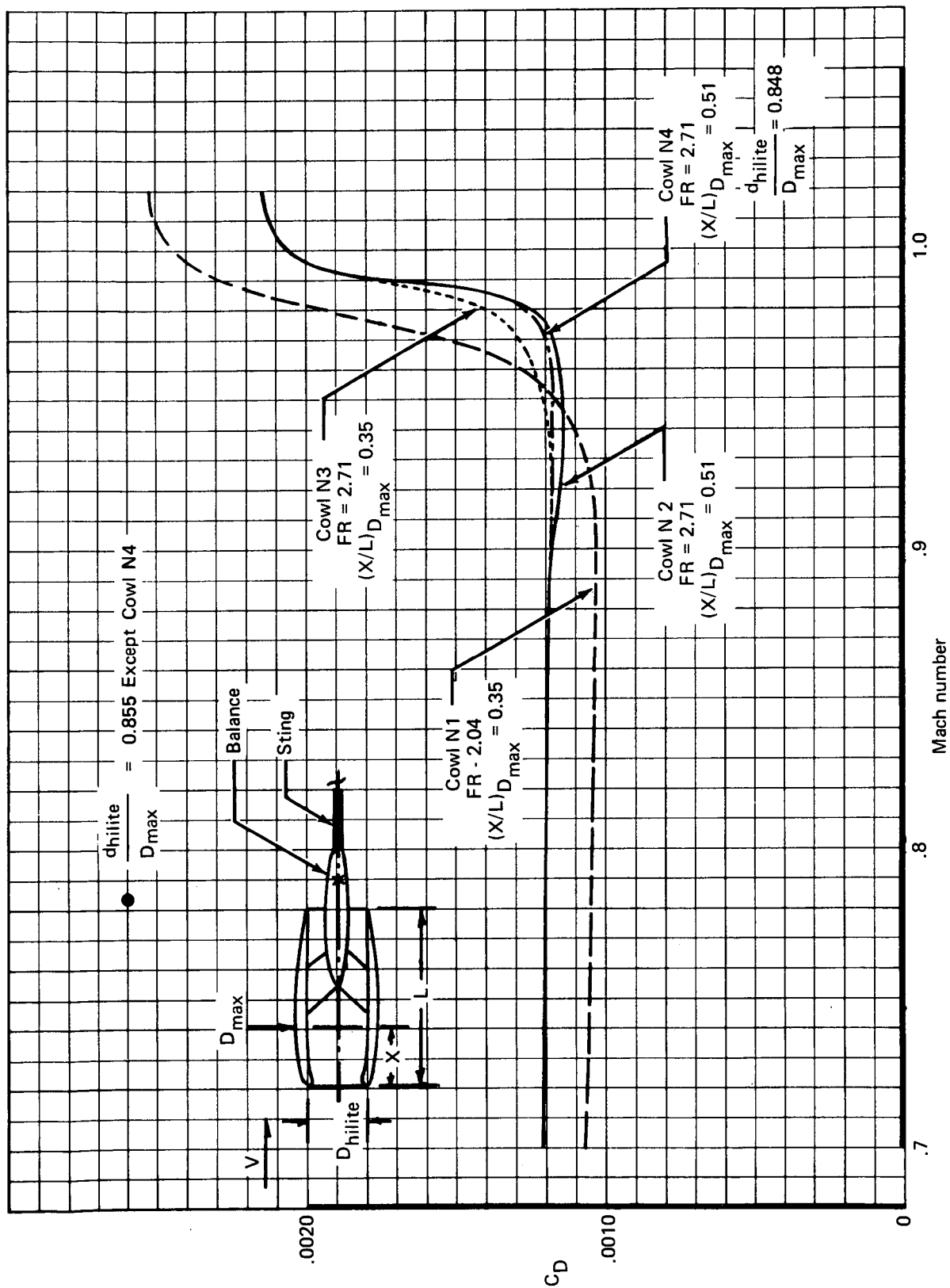


FIGURE 36.— NACELLE DRAG CHARACTERISTICS

Cowl contraction ratio

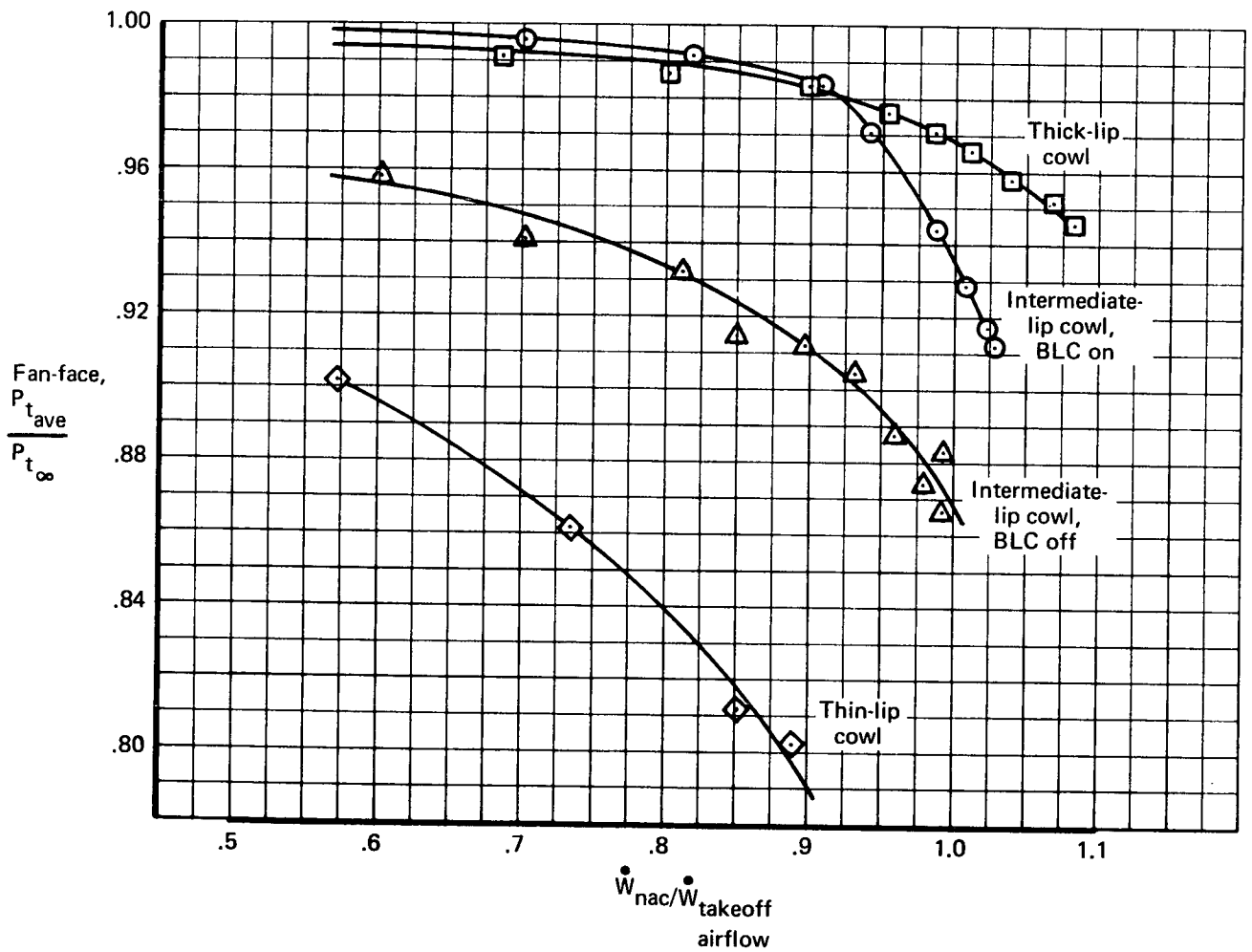
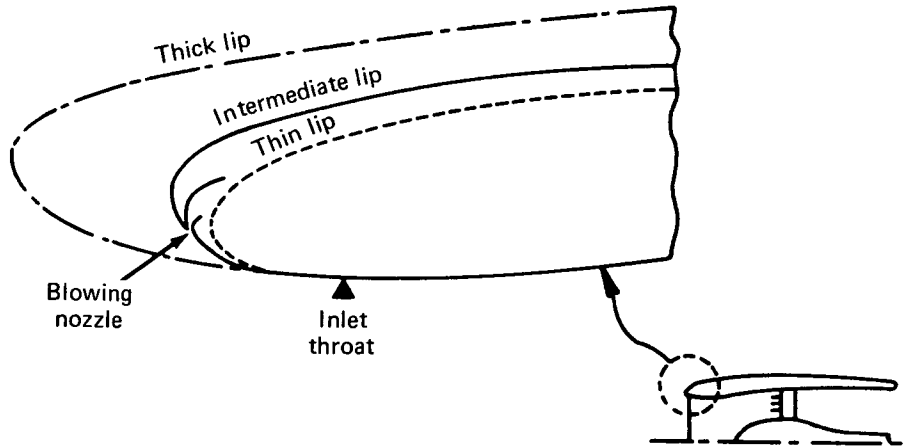


FIGURE 37.— STATIC PRESSURE RECOVERY

The design of the airplane cowl, and particularly the need for auxiliary inlet devices at low speed, is dependent upon whether the thick-lip approach will work. As an initial program, it is recommended that a family of cowls be designed, using existing methods, for use on a near-sonic transport. The family would cover a range of contraction ratios, fineness ratios, and inlet mass-flow ratios. Several of these cowls would be selected for isolated nacelle testing, which would establish—to first order, at least—the feasibility of using thick lip inlets at near-sonic speeds. Test measurements would include both pressure and force data. Assuming that one or more of these cowls would be reasonably successful, they would be integrated into a representative near-sonic transport configuration and tested.

It is anticipated that, following this initial program, better theoretical methods and a better understanding of the essential design constraints for the cowls would be available. At this point, a second design cycle should be initiated. A second family of cowls should be designed and tested, both isolated and integrated, into a representative complete model configuration.

Cost and Schedule

To cover possible different approaches and different applications of theoretical methods, it is recommended that two industry participants be selected to develop high critical Mach number cowls. Each of the cowl design cycles is estimated to require 1 year's time through the integrated configuration testing. The total funding necessary would be approximately \$750,000 per year, with about 75% spent on the wind tunnel testing and model construction.

A summary of the high-critical-Mach-number cowl development program is presented in figure 38.

Subsonic/Transonic Area Ruling

Potential Payoff

The objective of this program is to establish the sensitivity of configuration drag-rise to area-ruling in the subsonic/transonic regime. Included are studies of different degrees of area rule application, such as for a 0.90 design Mach number airplane versus a 0.98 Mach number design, and refinements in area ruling such as lift compensation. The payoff would be improved understanding of configuration essentials for designing at arbitrary subsonic Mach numbers with an associated increase in critical Mach number or a decrease in direct operating cost of up to 3%.

State-of-Readiness

The benefits of area ruling for transonic and supersonic flight have been developed sporadically since the early 1950s. Recently, the value of refined area-ruling has been demonstrated in the wind tunnel for the NASA high performance model. This configuration exploits a refinement referred to as stream-tube expansion area, or lift compensation, with an associated increase in critical Mach number of approximately 0.025.

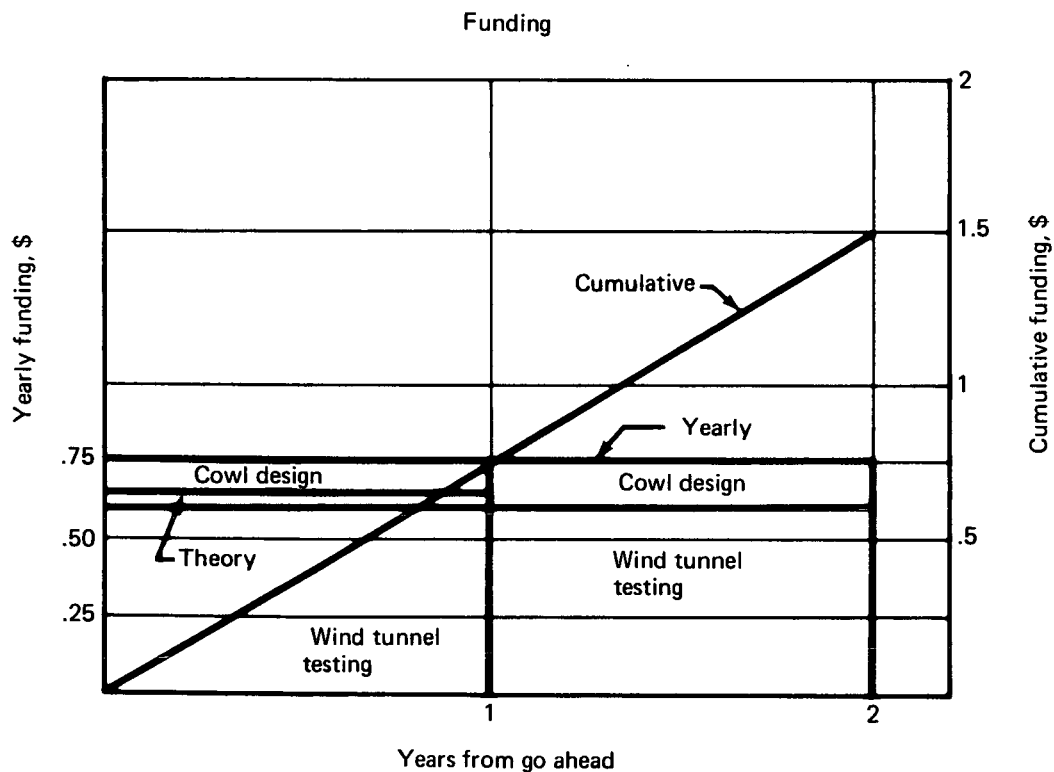
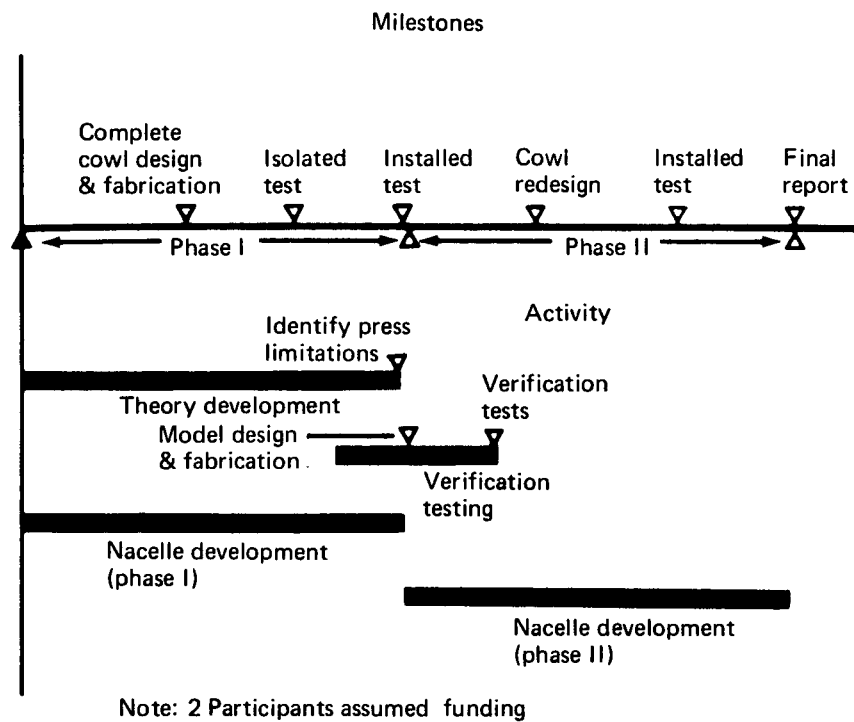


FIGURE 38.—HIGH CRITICAL MACH COWLS FUNDING SCHEDULE

Unfortunately, the mechanism of the stream-tube expansion effect is not well understood, and the effectiveness of the concept at lower Mach numbers is not known. Also, the value of area-rule refinements to other configuration details (such as body tailoring for low-wing configurations and/or wing tailoring for wing-mounted nacelles) has not been established. In the absence of proven theoretical methods for analyzing these details, wind tunnel testing is required.

Recommended Action

A generalized test program aimed at developing efficient configurations for typical high subsonic Mach numbers will permit the investigation of various subsonic/transonic area rule concepts. It is recommended that a two-phase wind tunnel program be conducted, aimed at four subsonic design Mach numbers from 0.85 to 0.98.

The first phase would consist of the design and test of wing-body-fin models, incorporating supercritical wings and area-ruling considered commensurate with the design Mach number. Two test cycles would be run, to permit analysis and refinement for the second cycle. Both force data and wing pressures would be measured.

The second phase would consist of adding typical wing-mounted nacelles. The object of this phase would be to demonstrate the configuration changes necessary to install the nacelles with a minimum change in basic wing/body characteristics. It is anticipated that three cycles of testing, analysis, and refinement would be required to optimize the configurations with nacelles on.

Costs and Schedules

The recommended program for subsonic/transonic area-ruling is estimated to require 2 years and cost approximately \$1.2 million (\$500,000 for Phase I, \$700,000 for Phase II). The program is summarized in figure 39.

Analytical Methods—Improved Design and Analysis Tools

Potential Payoff

The objective of the improved analytical methods program is to increase the usability of existing theoretical techniques and to develop advanced transonic analysis methods. The payoff from this work would be greatly facilitated theoretical analysis and a fundamental improvement in the ability to design efficient airplanes.

State-of-Readiness

Extensive use of the digital computer has been made over the past decade in mechanizing aerodynamic prediction and design techniques. In the subsonic flow regime, these techniques have been largely founded on the method of singularities, wherein configuration surfaces are represented by distributions of source and vortex or doublet elements. The resulting computer programs are capable of analyzing arbitrary three-dimensional configurations, including the effects of both lift and thickness. However, the usefulness of these tools is at present severely restricted by limited design capability, large computing time requirements, and high user skill

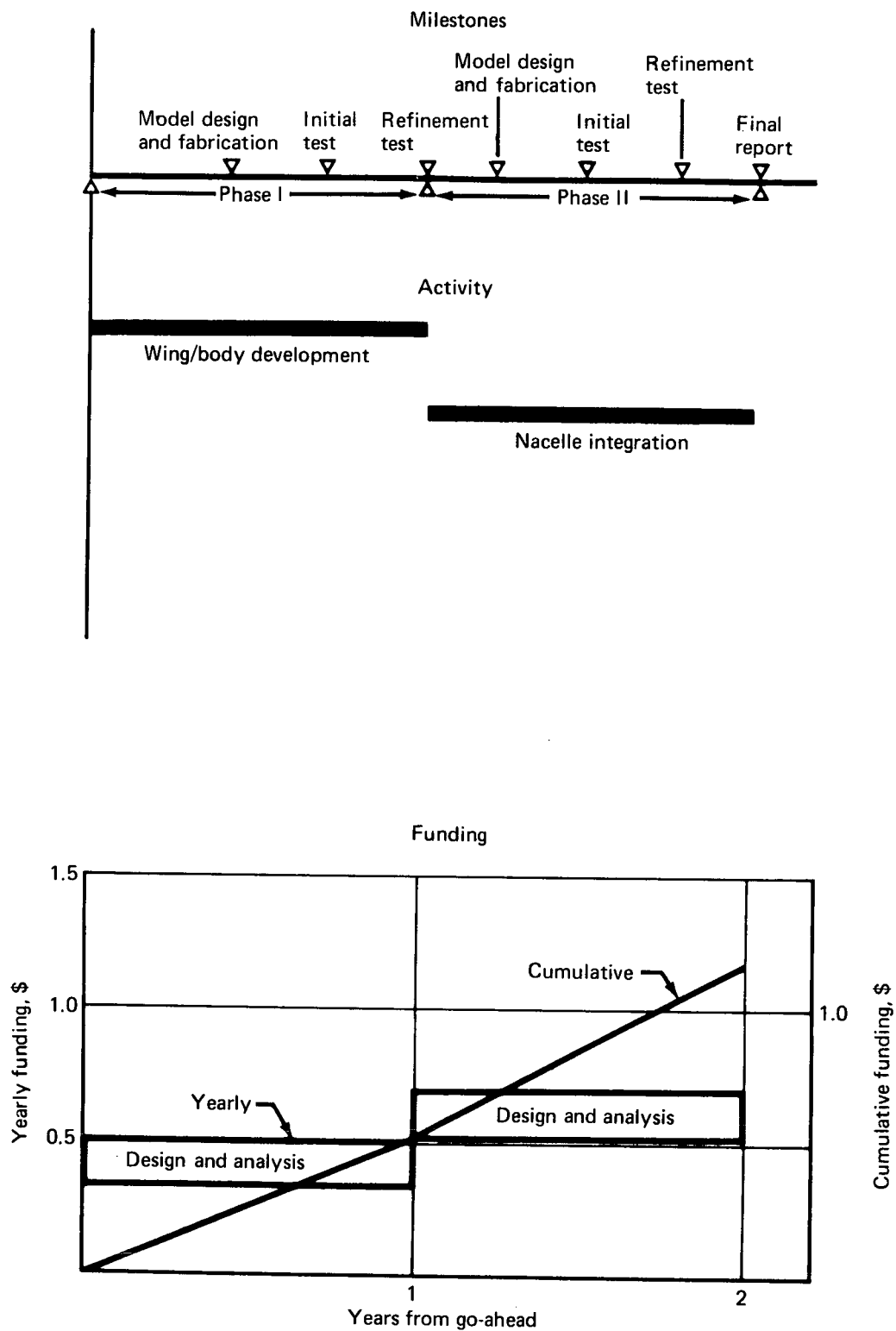


FIGURE 39.—SUBSONIC/TRANSONIC AREA RULING FUNDING SCHEDULE

level demands. These limitations can be reduced by incorporation of design singularity "building blocks," improved numerical techniques, and the assembly of more complete peripheral input modules. Such refinements are badly needed in order to introduce the methods to a wider circle of users.

Extension of analysis capability into the transonic regime will greatly assist the aerodynamic development of efficient near-sonic airplanes. The finite difference approach to solution of the steady transonic equations, currently pursued by several investigators, shows promise and needs to be pressed vigorously. This work is currently limited to two-dimensional problems and simple three-dimensional wings but is thought to be capable of extension to complex three-dimensional configurations. Availability of steady transonic solutions of this type would yield further benefits in that they should make possible the solution of unsteady flow problems. Development of such tools would therefore increase the understanding of the transonic flutter phenomenon, with attendant payoffs in increased airplane structural efficiency. Further refinements of the basic method could include the incorporation of three-dimensional boundary-layer analyses which would lead eventually to the capability of exploring shock-boundary layer interactions, both static and dynamic.

Recommended Action

It is recommended that a two-part program be implemented to expand current theoretical design and analysis capability:

- Improve the usability and flexibility of existing subsonic three-dimensional computer programs by incorporating nonlinear design capability, refined numerical techniques, and automated input packages.
- Pursue the development of three-dimensional transonic analysis capability, initially for the steady-flow case, but with subsequent extension to the solution of dynamic problems and shock wave-boundary layer interactions.

Costs and Schedules

The recommended funding for furthering the development of theoretical aerodynamic prediction methods is summarized in figure 40. This includes estimates for researchers and programmers at several establishments. Computing time estimates are not taken into account. It is emphasized that a high level of cooperation between research groups and industry is felt to be a very desirable element in such a program.

Novel Design Concepts

Potential Payoff

The objective of this program is to develop and analyze configurations which appear to offer significant aerodynamic, acoustic and/or structural weight benefits. Emphasis would be given to the evaluation of high technical risk concepts which, if successful, would provide a comparatively large improvement in airplane performance or noise. Potential payoffs could amount to as high as 10% better payload-range performance and/or 10 PNdB noise improvement.

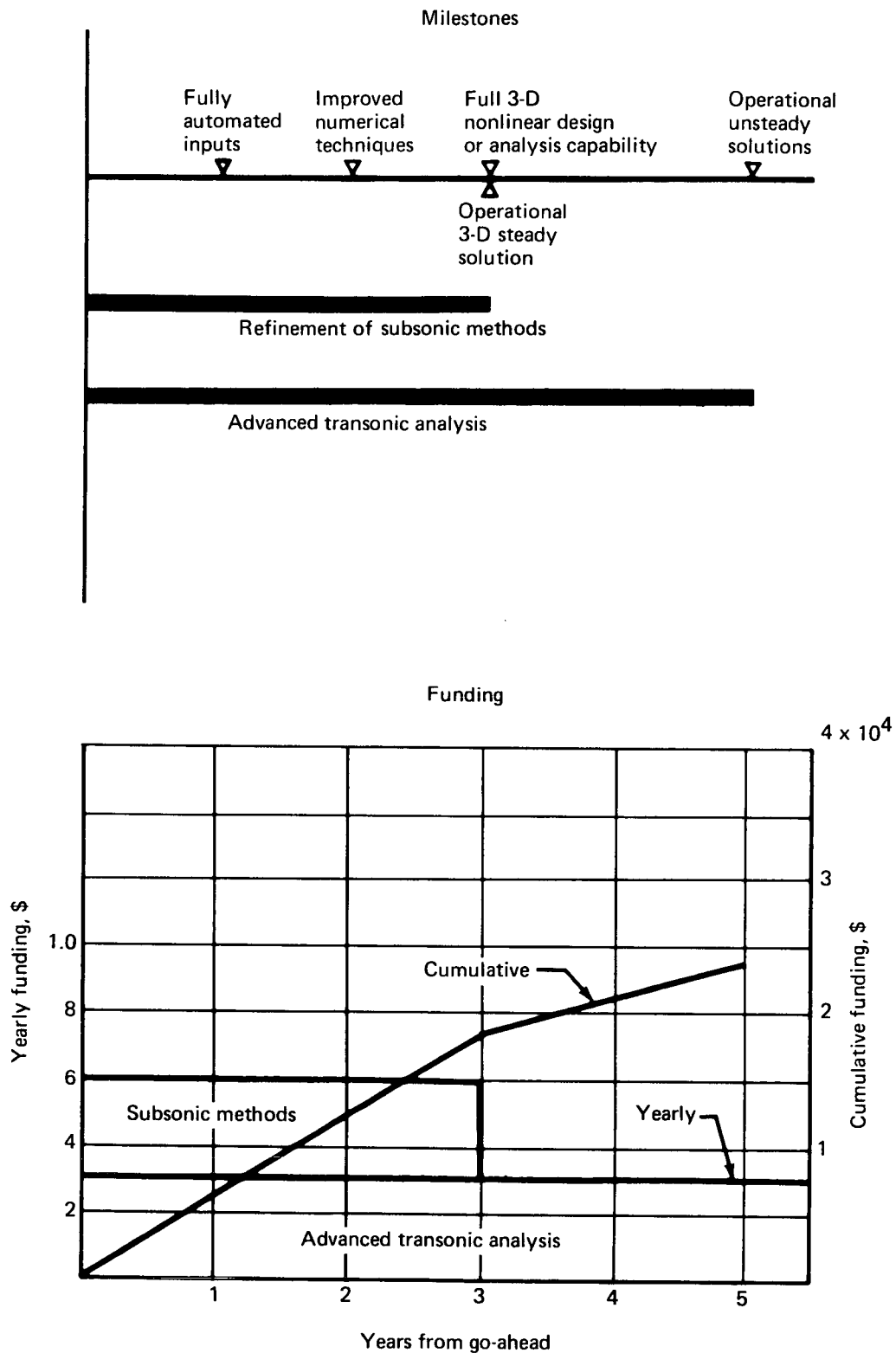


FIGURE 40.—ANALYTICAL METHODS—IMPROVED DESIGN & ANALYTICAL TOOLS FUNDING SCHEDULE

A good illustration of a design concept of this type is the “slipper” nacelle transport shown in figure 41. The configuration shows the favorable features listed in figure 41. Both high and low-speed wind tunnel development testing was initiated in support of this program.

For application on a swept wing, the interference drag of the slipper nacelle can be quite high unless proper integration measures are taken. Figure 42 presents the improvement achieved in reducing interference drag through applying streamline contouring techniques to the nacelle installation. The uncontoured, cylindrical nacelle has unacceptable drag penalties. With tailoring, this penalty was reduced to about 10 drag counts. Oil-flow and isobar pressure comparisons between the various slipper nacelle simulators (plugged, flow, and blown) and the clean wing are made in figure 43. Reasonable correlation is shown although pressure peaks still exist in the inboard side of the nacelle. Further refinement should allow the slipper nacelle to be installed for the same drag level as the strut-mounted nacelles.

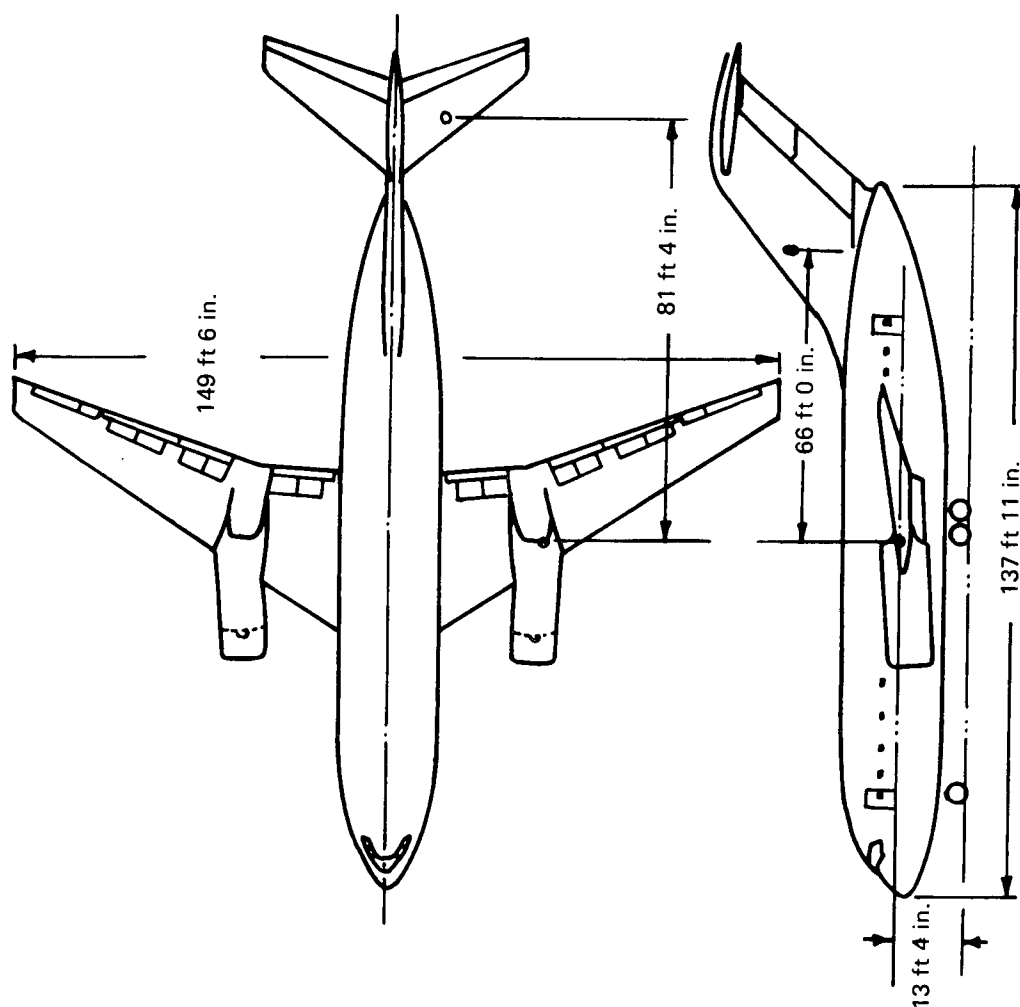
A low-speed blown model was tested also to evaluate the influence of this installation on flap performance. Both takeoff and landing settings were investigated as shown in figure 44. Test results are presented in figure 45 for three levels of blowing representing idle to takeoff power settings. Significant lift augmentation occurs with the slipper installation compared to the strut-mounted nacelle with no flap impingement.

State-of-Readiness

Numerous novel design concepts have been suggested by government agencies and others which offer large potential benefits in a particular technical area. In many cases, however, the technical risk in other areas is increased. Only through development of well-defined airplane configurations followed by detailed evaluation can the true benefits of these concepts be firmly established.

In addition to the “slipper” nacelle transport discussed above, figure 46 depicts several other concepts (but certainly not all) that should be considered for this type of study.

- Vorticity Control Transport—This concept is inspired by NASA test results of a tip-mounted high-bypass fan-jet engine installation on a straight wing. These data indicate a reduction of more than 20% in drag-due-to-lift resulting from wing tip vortex control provided by the engine nacelle and the nonrotating high energy fan wake.
- Quiet Engine Transport—This concept attacks the problem of obtaining lower noise levels at the airport and in the surrounding community. It provides for extensive use of acoustic lining both ahead of and behind the engines. A configuration of this type using advanced lining technology could provide noise level reductions as high as 20 PNdB below FAR 36.
- Antisymmetric Transport—This concept has appeared in the literature many times in past years. It offers superior aerodynamic efficiency for both low speed and transonic flight. Other potential advantages over swept-wing aircraft are claimed and include improved balance, continuous wing structure, and favorable aeroelastic properties. Many configuration arrangements are possible. The one depicted in figure 46 was developed by NASA Ames.



*Payoff:

Lower installation weight
(3000 lb/airplane)

Lower deck height
(20 inches)

Reduced gear weight
(600 lb/airplane)

Less ingestion problems
(highlight 21 inches higher)

Potential reduction in primary
jet noise

Power lift augmentation

*Relative to wing strut mounted nacelles

FIGURE 41.—GENERAL ARRANGEMENT SLIPPER NACELLE CONFIGURATION MODEL 755-278

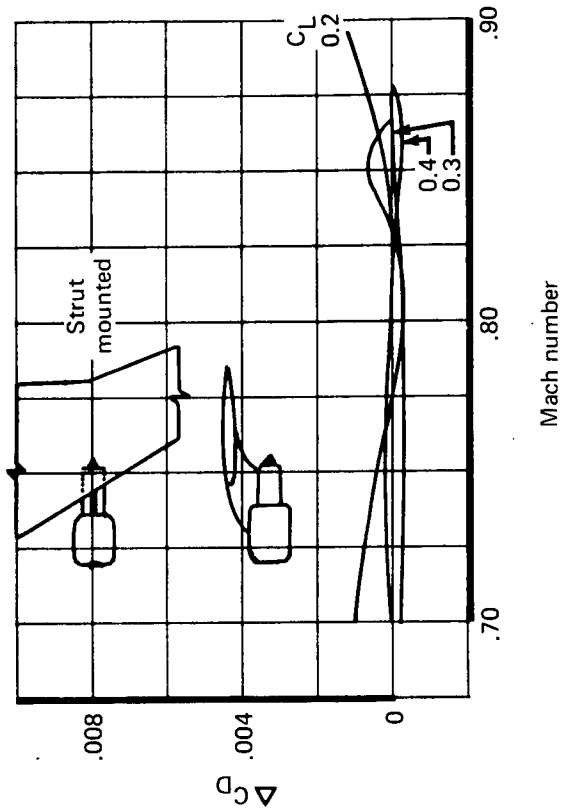
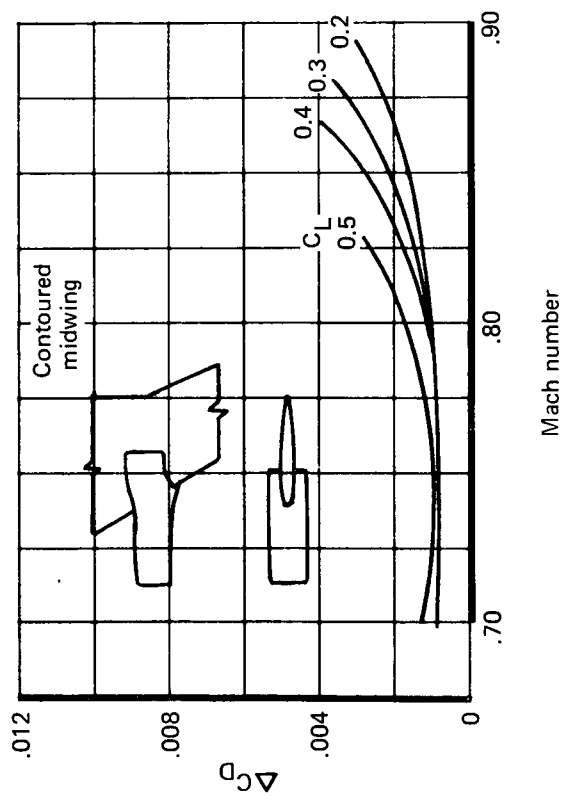
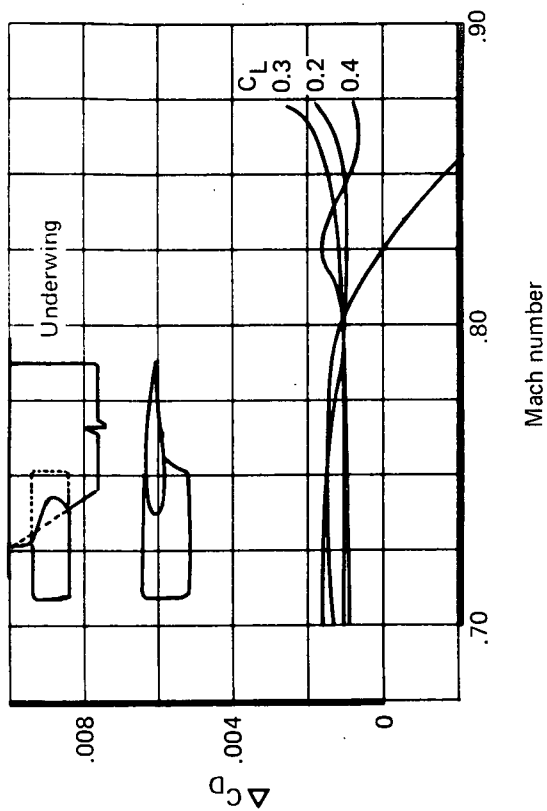
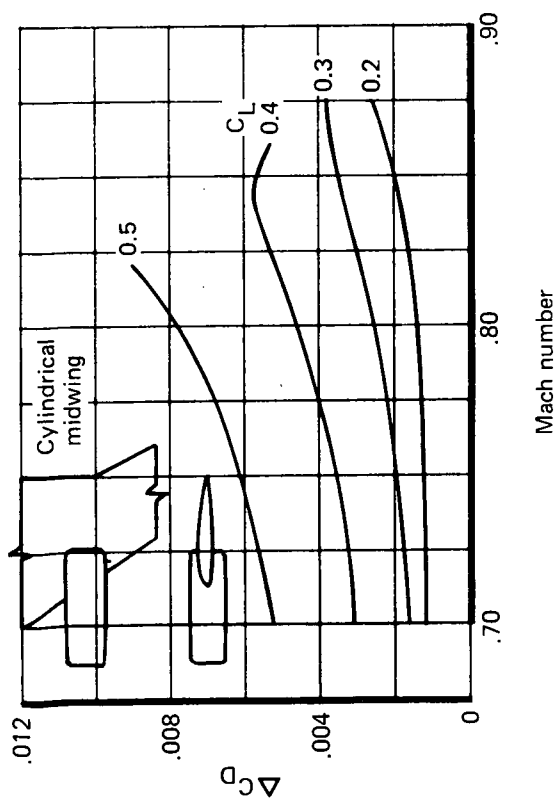


FIGURE 42.—NACELLE INTERFERENCE DRAG

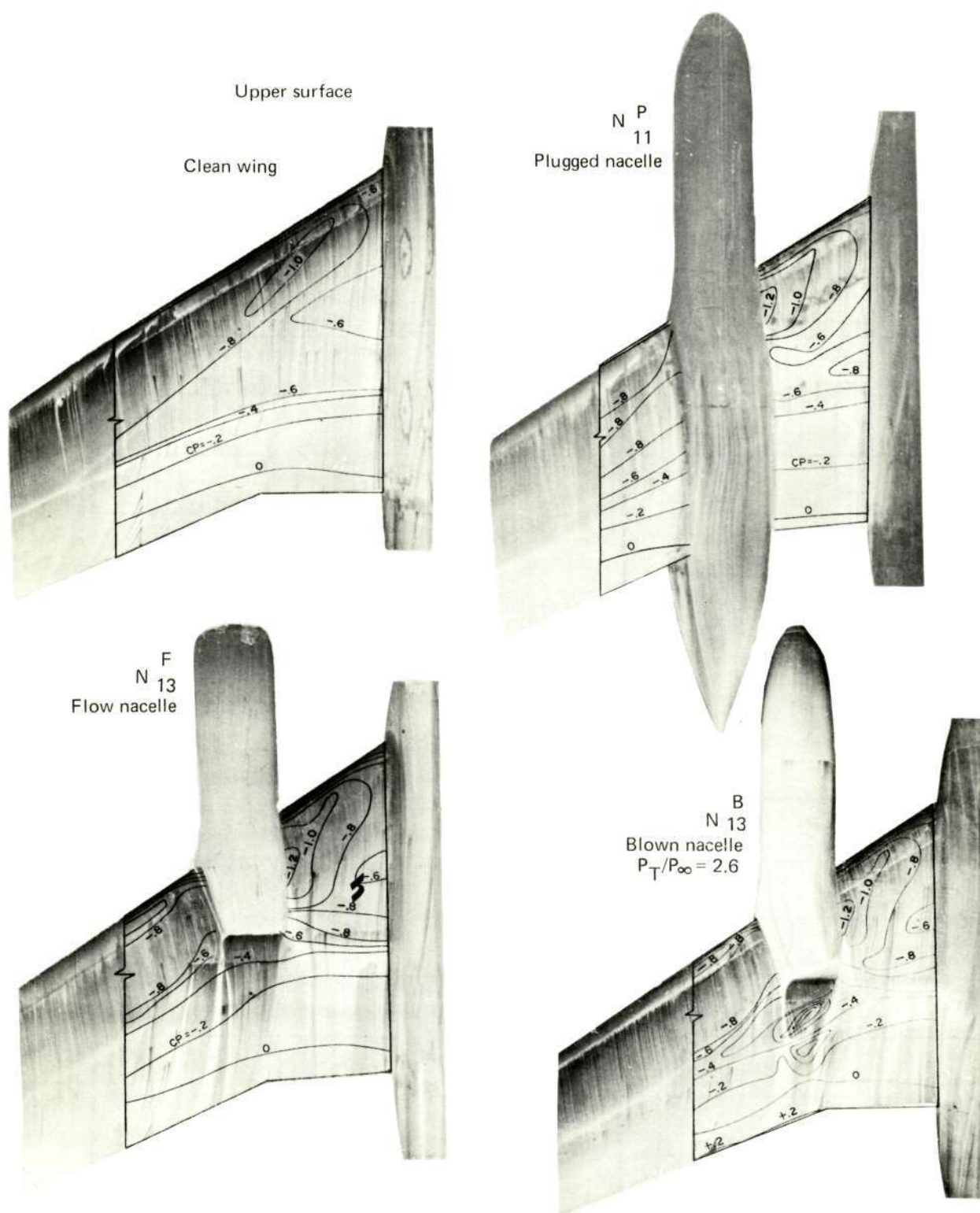
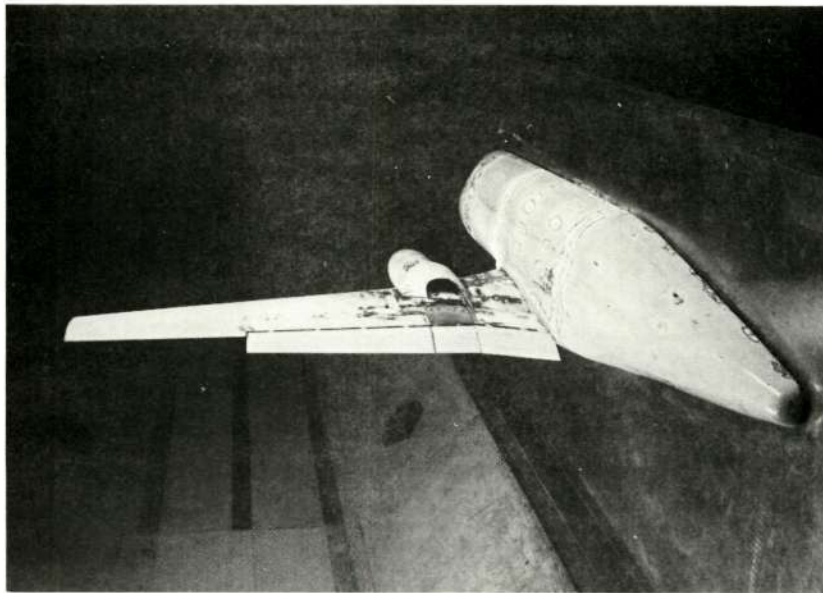
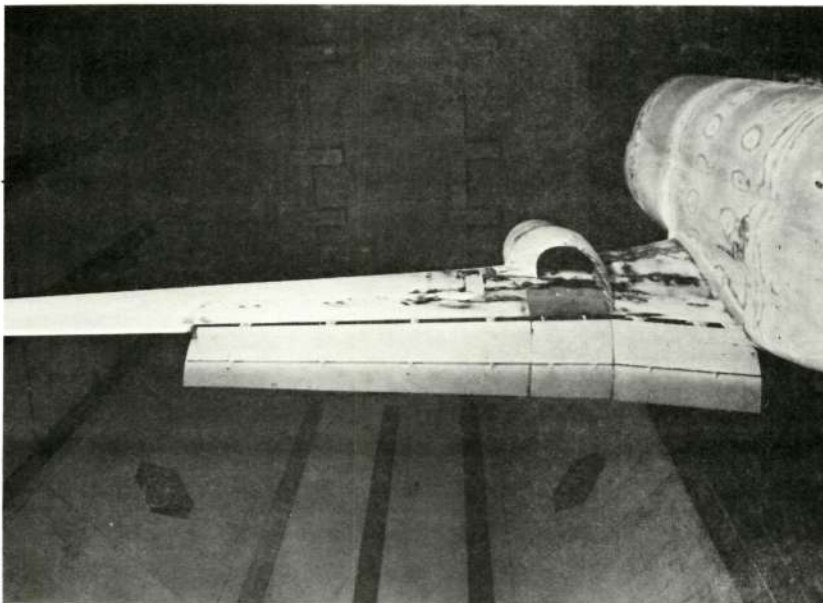


FIGURE 43.— MIDWING NACELLE, $M = 0.85$ $C_L = 0.42$



Takeoff flaps



Landing flaps

FIGURE 44.— LOW-SPEED BLOWN NACELLE TESTING

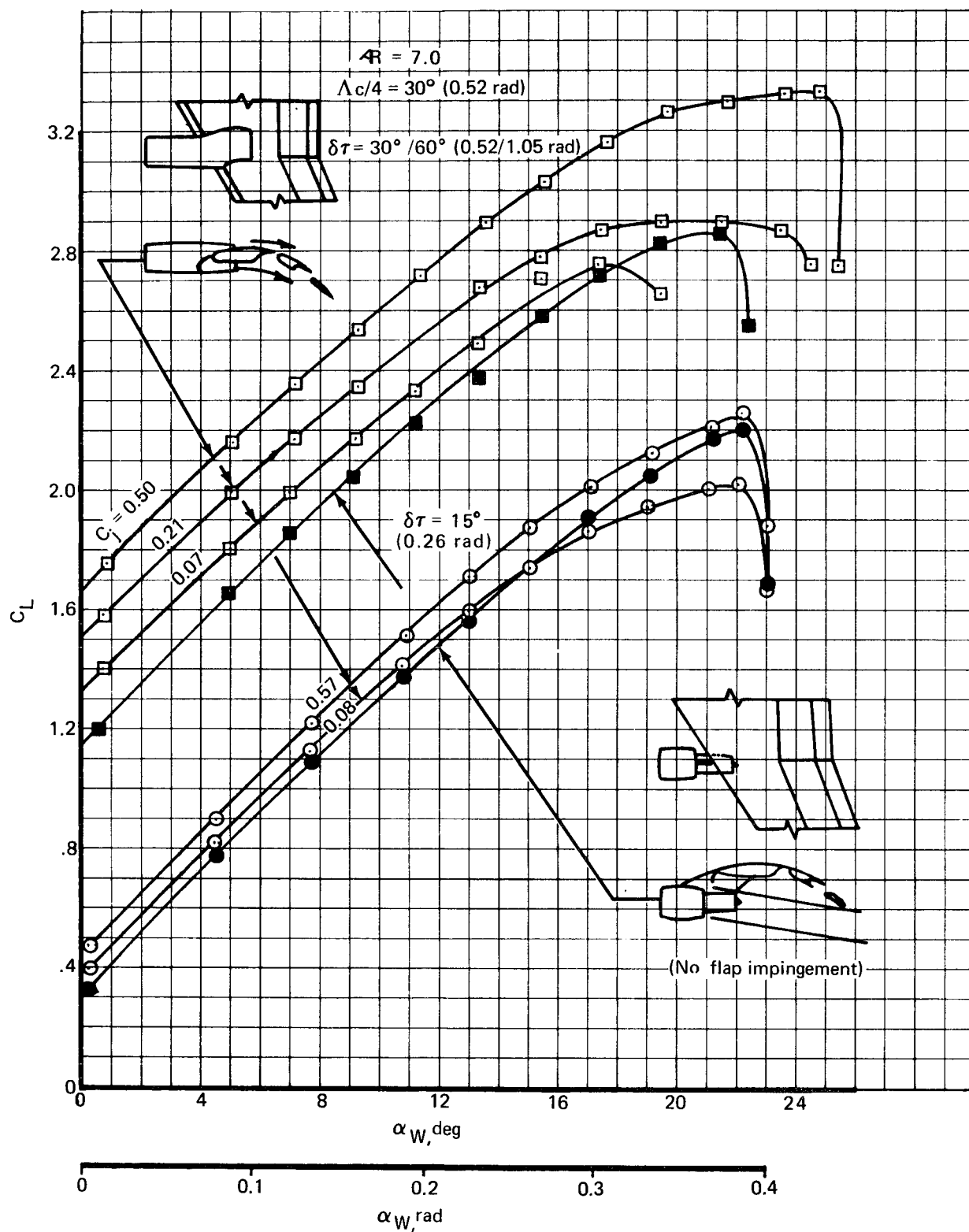
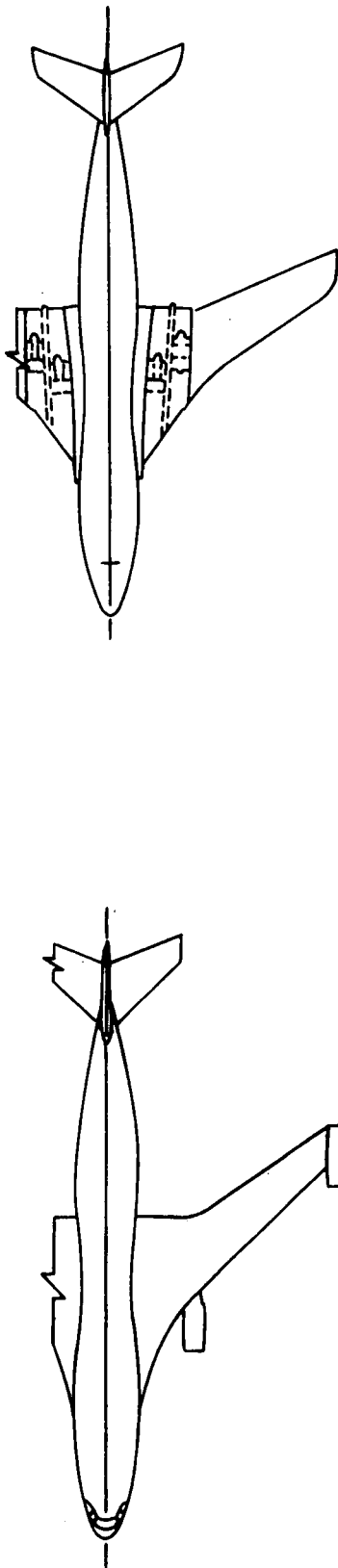
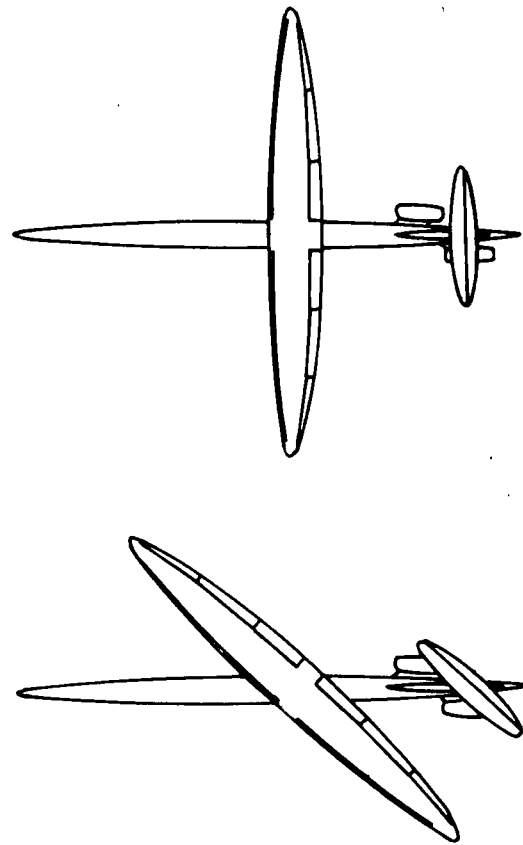


FIGURE 45.—NACELLE LOCATION AND THRUST INFLUENCES ON LIFT



VORTICITY CONTROL TRANSPORT

QUIET ENGINE TRANSPORT



ANTI-SYMMETRIC TRANSPORT

OPTIMUM BALANCE TRANSPORT

FIGURE 46. — TYPICAL NOVEL DESIGN CONCEPTS

- **Optimum Balance Transport**—Conventional airplanes operate with a down tail load during takeoff climbout and landing approach. This is true also for most normal cruise flight. Moderate penalties in drag and in maximum lift capability are therefore inherent with a conventionally balanced configuration. The advent of supercritical wing technology has focused more attention on this aspect because of larger trim drag penalties for cruise. This is a result of the aft loaded section producing more negative C_{m_0} and also the manner in which the supercritical section develops lift as angle of attack is increased at design speed. Figure 47 presents trim drag increments from wind tunnel data at Mach 0.98 and $C_L = 0.4$ for the NASA High Performance model. The reduction in high speed trim drag for a cruise c.g. location of 50% MAC compared to the c.g. of 20% for conventional balance is 20 drag counts. Rearward displacement of airplane c.g. also produces trim drag benefits in low-speed operation, resulting in appreciable increases in flaps-down lift-to-drag ratio for a given flap setting and total lift coefficient. These benefits may be realized in improved field performance, or improved climb performance and reduced noise levels.

Recommended Action

Activities for this program would include an initial phase of conceptual design studies of several novel concepts. Aerodynamic design studies would be performed in depth and this work would be supported by other design disciplines (control of flight, structures, etc.). These studies would lead to selection of more promising configurations for detailed analysis. This phase of the work would then include construction and testing of necessary wind tunnel models to provide a sound basis for aerodynamic estimates. Time would be allowed for refinement cycles as required.

Costs and Schedules

To cover possible different approaches and to be sure that all concepts of merit are included, it is recommended that two industry participants be selected to study novel design concepts. The program would cover a 2-year period in order to allow time for wind tunnel model testing and possible configuration refinement cycles. Required funding would be 6 million dollars assuming two industry participants.

A summary of the novel design concepts program is presented in figure 48.

Interference-Free Transonic Test Section

Potential Payoff

The objective of this program is to develop a test section which minimizes aerodynamic interference and a mounting system for aft body closure testing in the transonic regime. The payoff would be greatly reduced risk for new programs because of increased confidence in the wind tunnel measurements. In addition, reduced cruise drag and improved high-speed performance would be achieved through configuration refinements in an interference-free environment.

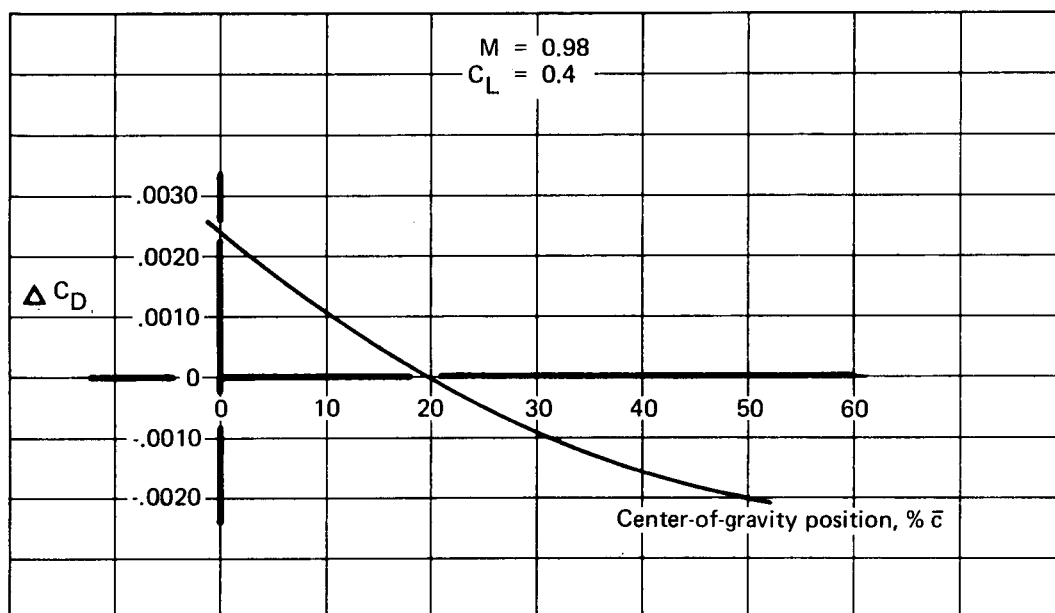
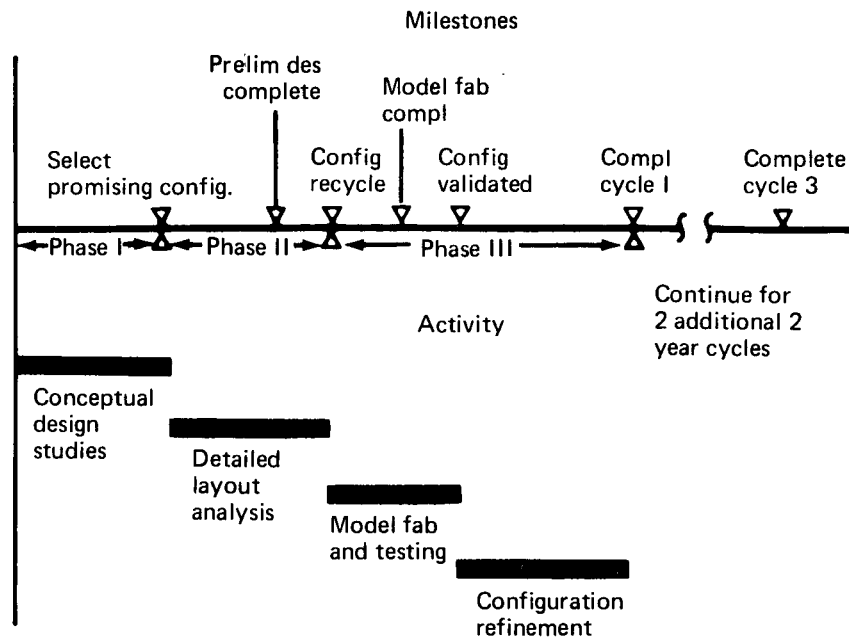


FIGURE 47.—TRIM DRAG SENSITIVITY



Note: Two participants assumed

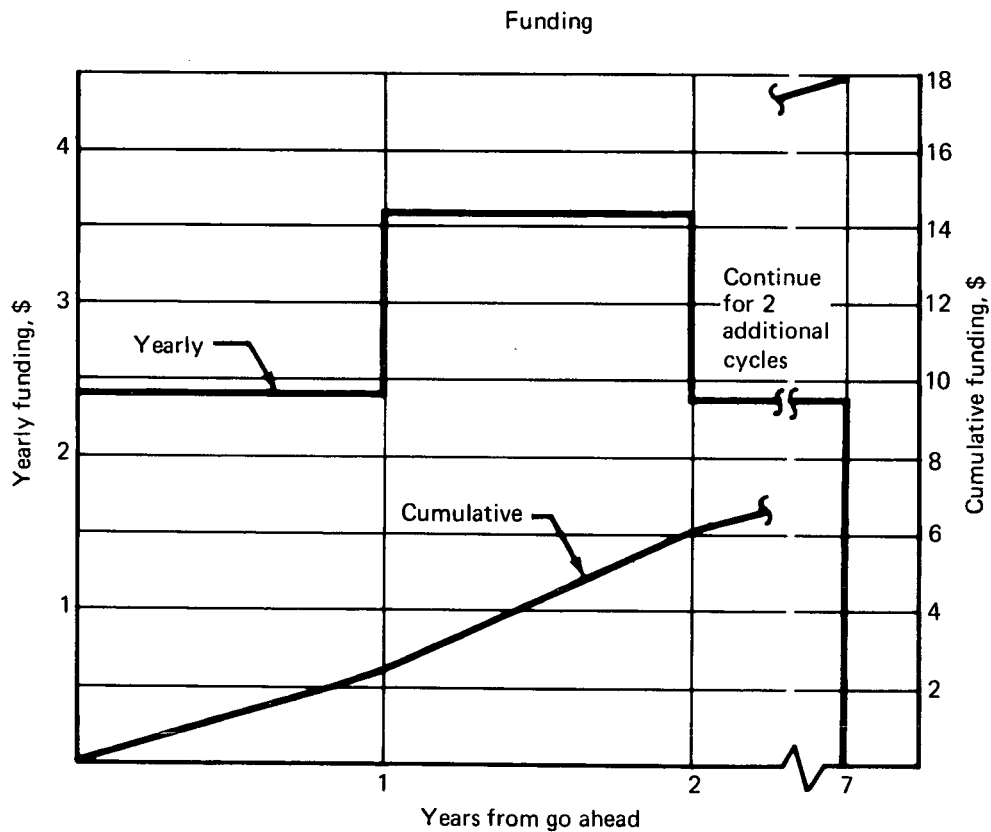


FIGURE 48.—NOVEL DESIGN CONCEPTS FUNDING SCHEDULE

State-of-Readiness

Current wind tunnel facilities are limited in accuracy for operation near Mach 1.0 because of blockage and interference in the test section. This effect has been explored to some extent by testing bodies of revolution of various sizes in the Boeing and AEDC transonic wind tunnels. Three bodies were tested, designated B₂, B₃, and B₄ in figure 49, which were geometrically similar but of different lengths.

Test data using a standard transonic wall configuration—16 slots with an open area ratio of 11.3%—showed negligible interference up to a Mach number of 0.97. The pressure data in figure 50, taken at $M = 0.90$, are typical of this regime. Above $M = 0.98$, significant variations in pressure distribution and shock location occur as a function of body length as illustrated in figure 51 at $M = 1.0$. The shocks on bodies B₃ and B₄ are 24 inches aft of the nose, which is behind body B₂. It is believed the shocks are the result of inflow from the plenum into the test section. Reducing the wall slot open area (porosity) to 3.5% reduces this inflow and wall interference as shown in figure 52.

Similar data have been measured by NASA, showing substantial wind tunnel wall interference above $M = 0.98$.

These results were obtained with slender bodies at Mach numbers close to 1.0; it is probable that similar difficulties may exist at lower Mach numbers with less-slender bodies and lifting configurations.

No generally accepted model mounting system has been developed for aft body configuration testing in the transonic regime. The conventional sting mounting does not allow aft body closure and upsweep testing due to the presence of the sting system. Because of the relationship of the aft body closure to overall area-ruling effects, significant interference effects may result from the sting mount. Limited development has been done on an extended plate mount shown in figure 53 used in testing a flowthrough "S" duct installation on a near-sonic configuration. Other mounting systems need to be evaluated and compared to the plate approach.

Recommended Action

The following activities are recommended to develop an interference-free wall configuration for transonic testing. A calibration series of models should be built and tested—different size models in a series of fineness ratios—to determine wall interferences as a function of model size, wall porosity and Mach number. Corresponding data should also be obtained from flight test "drop" models. Wall "fixes" should be investigated in a relatively small pilot tunnel, and promising solutions tested in a typical transonic tunnel.

With respect to mounting system development, several competitive mounting systems should be tested and evaluated. These would include the extended plate mount (floor mounted), a similar "blade" type mount for use with the sting system, and a wing tip "grabber" arrangement. Other similar concepts should be considered for feasibility.

Model	Length, m	$(L/D)_{\max}$	D_{sting} , m	Blockage, %
B ₂	0.508	9.0	0.0112	0.031
B ₃	1.016	9.0	0.0224	0.122
B ₄	1.524	9.0	0.0336	0.275

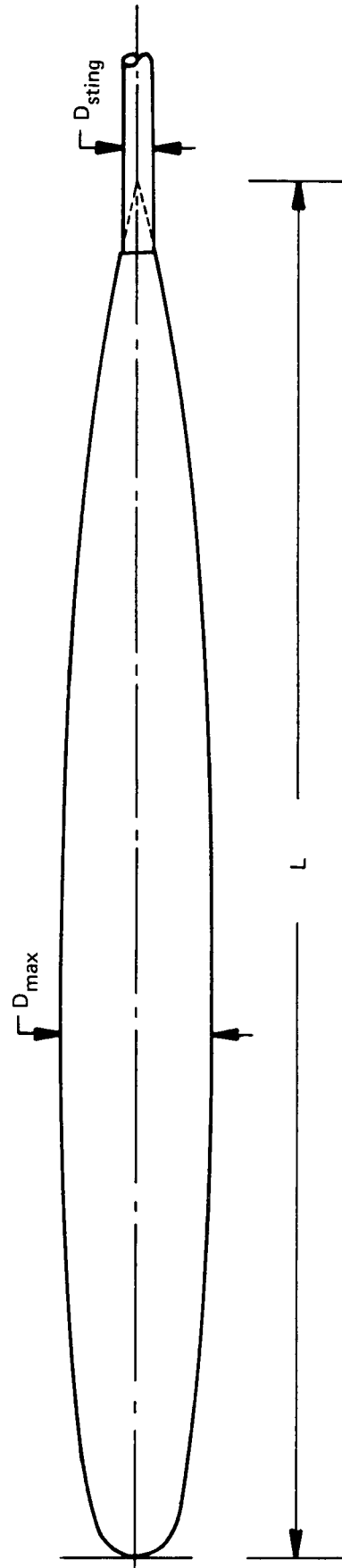


FIGURE 49.— BOEING TRANSONIC WIND TUNNEL WALL INTERFERENCE TEST

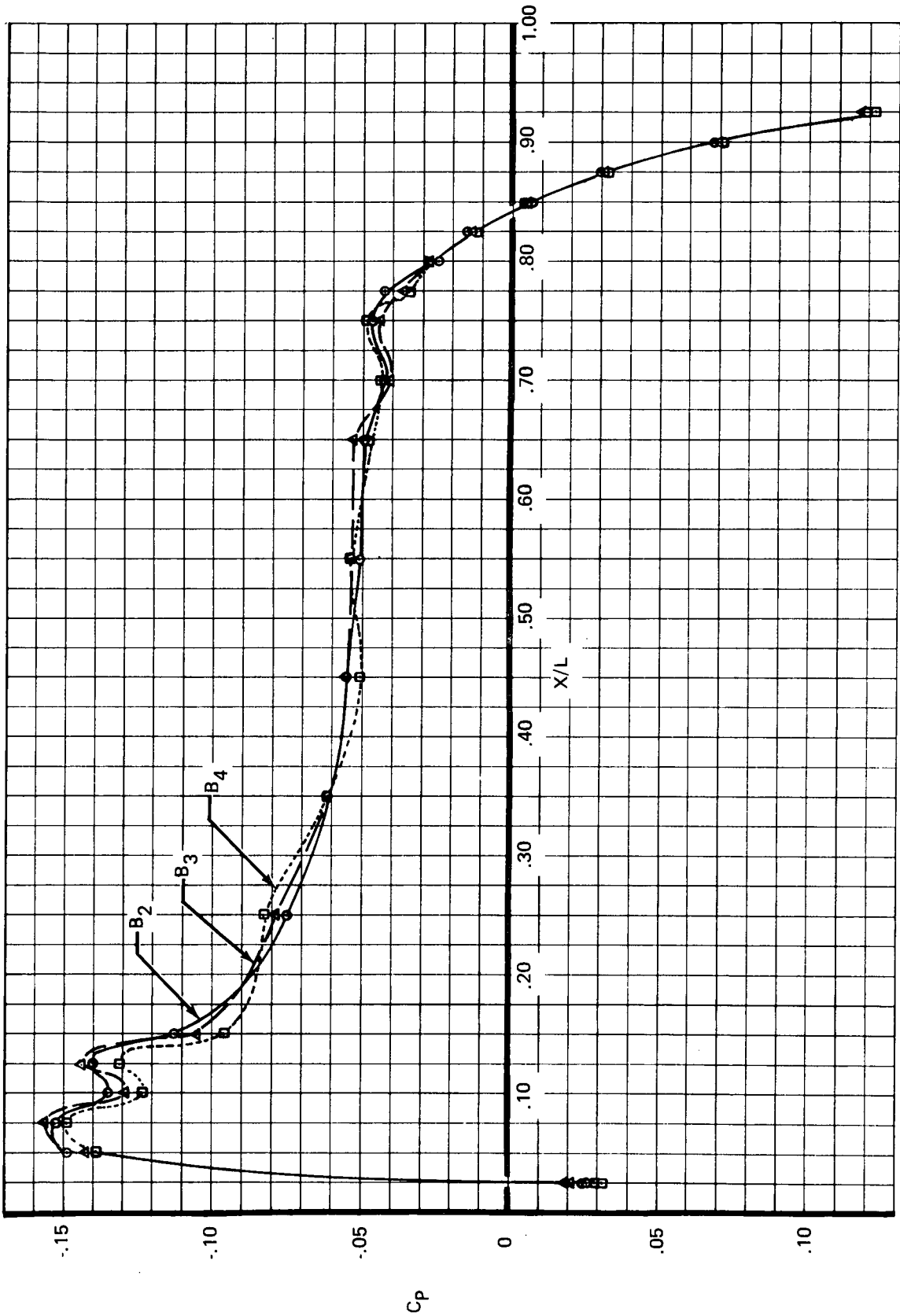


FIGURE 50.— BODY PRESSURES ON MODELS OF VARIOUS LENGTHS, SLOTTED WALL, 11.3% OPEN, $M_\infty = 0.90$

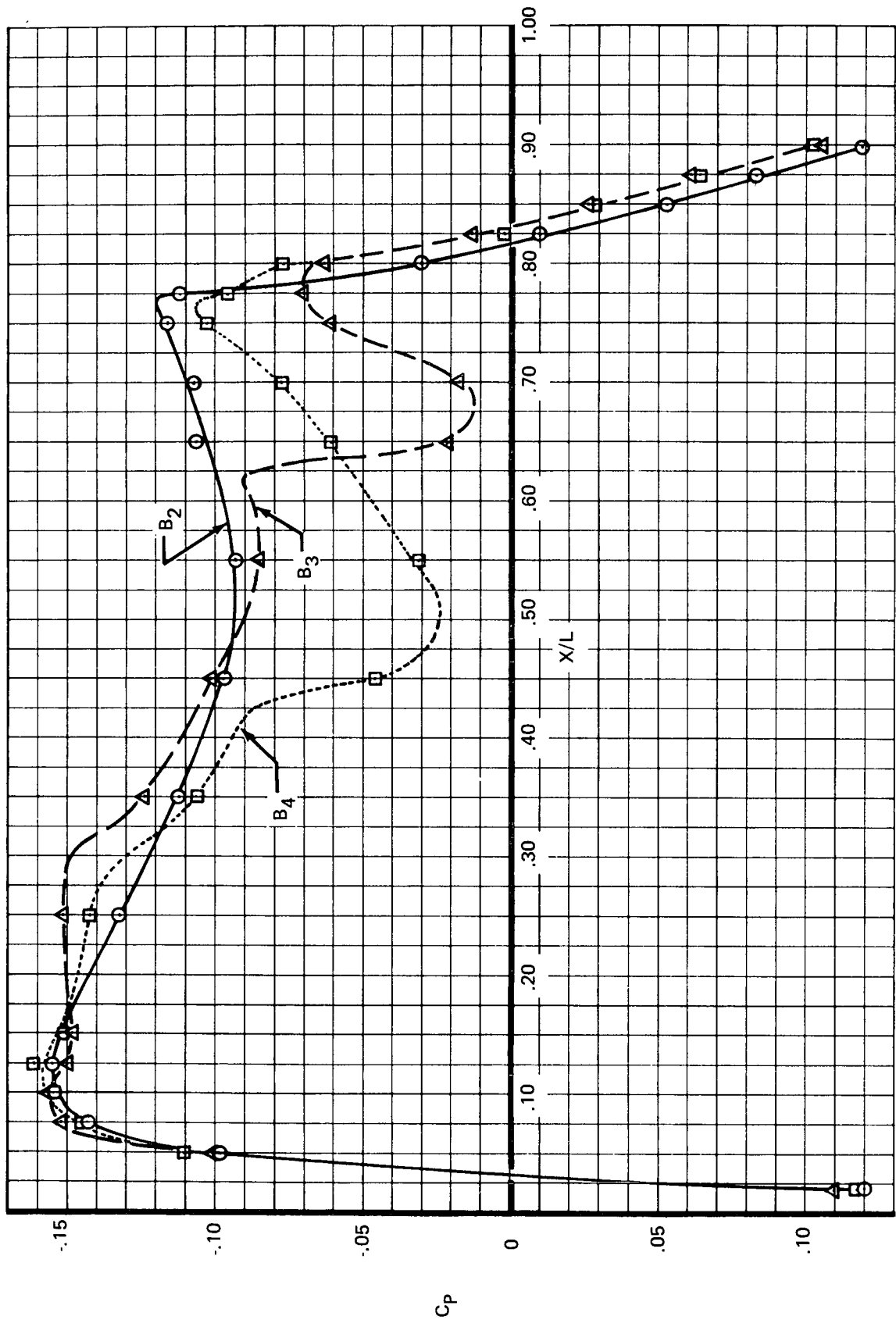


FIGURE 51.—BODY PRESSURES ON MODELS OF VARIOUS LENGTHS, SLOTTED WALL, 11.3% OPEN, $M_\infty = 1.00$

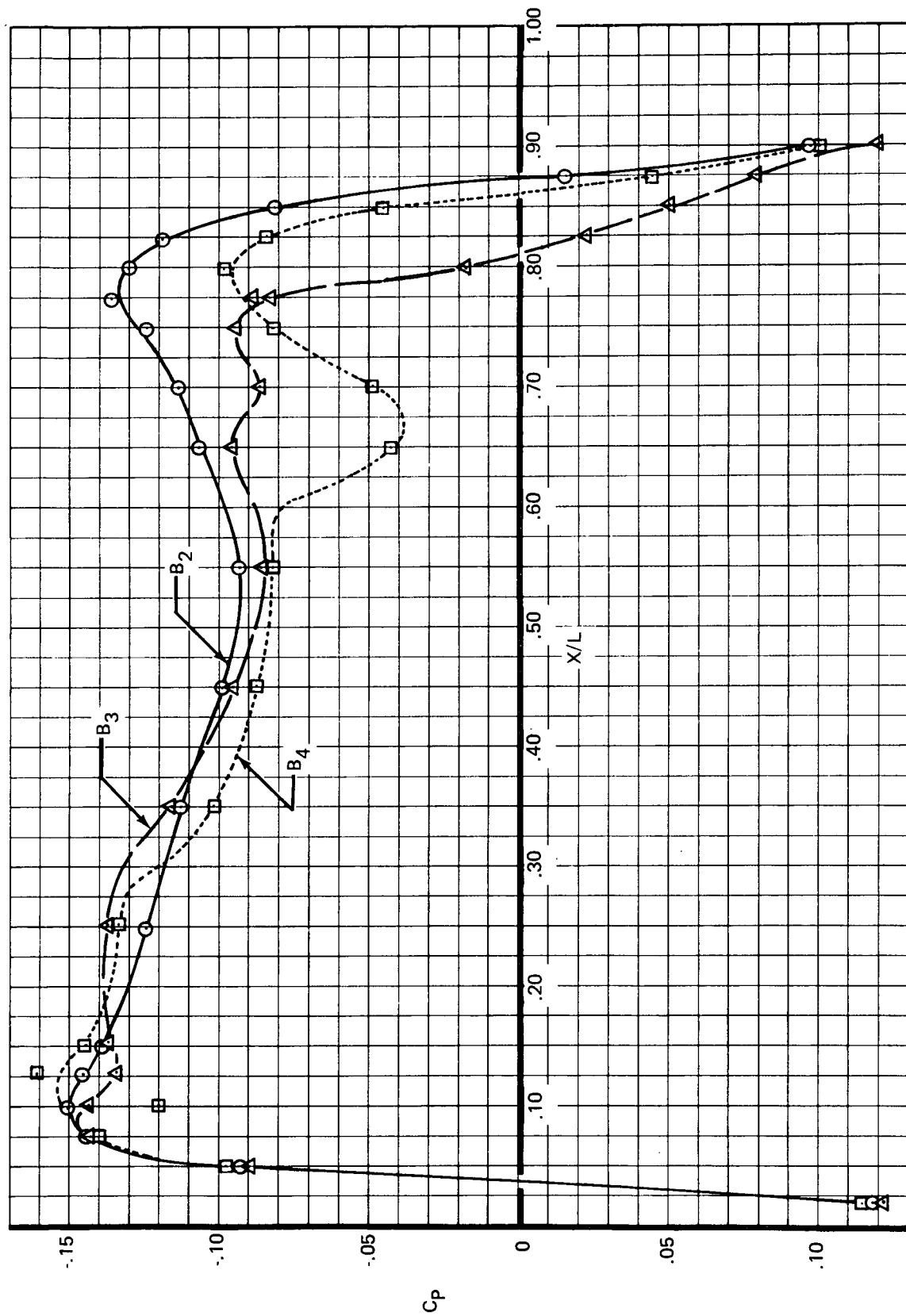
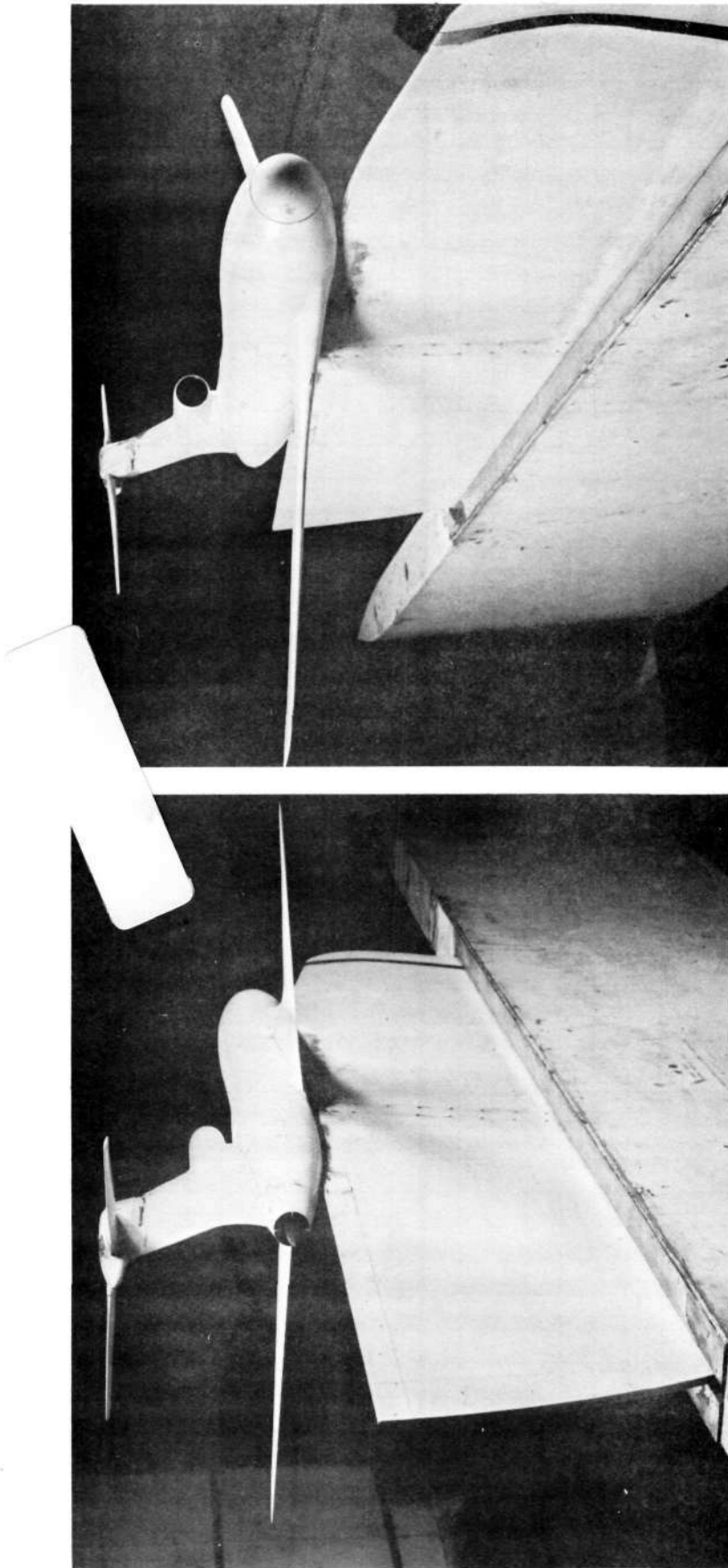


FIGURE 52. — BODY PRESSURES ON MODELS OF VARIOUS LENGTHS, SLOTTED WALL, 3.5 % OPEN, $M_\infty = 1.002$



Flow-through "S" duct

FIGURE 53.— PLATE MOUNT FOR TRANSONIC CLOSURE TESTING

Costs and Schedule

The recommended program to develop an interference-free transonic test section is estimated to require approximately 3 years. In the first year, at a cost of approximately \$830,000, the calibration model series would be defined and tested, both in typical and very large wind tunnels, and corresponding drop model data obtained. Test section "fixes" in the pilot wind tunnel would be evaluated in the second year, at a cost of approximately \$400,000. In the third year, a typical transonic tunnel would be modified. The cost of the modification would probably be of the order of \$500,000 to \$1,000,000.

The mounting system development and evaluation would require approximately 1 year, and is estimated to cost approximately \$350,000. The recommended programs and costs for the interference-free transonic test section development are summarized in figure 54.

Because of its unique wind tunnel facilities, it is felt that this program could best be accomplished by the NASA, with appropriate industry support.

Flight/Wind Tunnel Correlation

Potential Payoff

The objective of the flight/wind tunnel correlation program is to define the measured characteristics of representative airplanes. These measurements will provide the basis for improving current aerodynamic prediction techniques. The payoff will be improved accuracy in estimating the performance of new airplanes.

State-of-Readiness

Present methods of predicting aerodynamic lift-drag characteristics are reasonably accurate and have been generally confirmed by limited comparisons with flight test data. These methods could be considerably improved, however, with some concentrated wind tunnel and flight test data analysis. In particular, it is felt that further correlation and refinement in prediction techniques would be appropriate in the case of high-lift configurations, in view of the importance of low-speed aerodynamic performance on community noise levels.

Recommended Action

Interference-free wind tunnel data, both flaps up and flaps down, would be obtained for models of typical current airplanes. Among these would be the NASA F8 with supercritical wing. Transition strip techniques would broadly conform to current NASA recommendations as applied to the supercritical wing development, although it is recommended that exploratory trip investigations be performed on each individual configuration as a prelude to detailed testing.

Corresponding flight test data are assumed to exist; however, for cases where the information is incomplete, the necessary flight test experiments would be performed. Care would be taken to ensure that the necessary flight test "bookkeeping" corrections with regard to thrust and fuel consumption were applied.

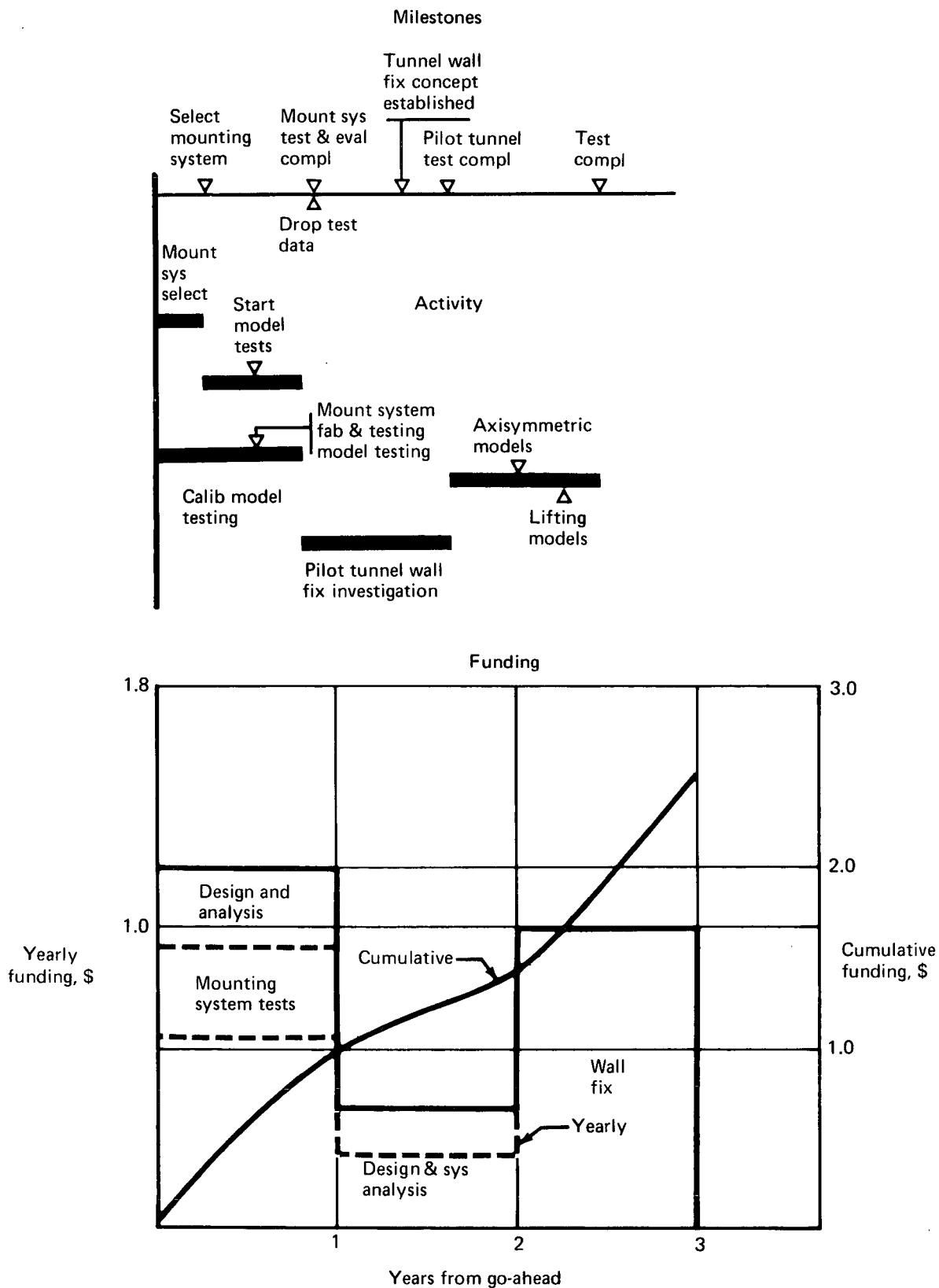


FIGURE 54.—SCHEDULE AND COST "INTERFERENCE FREE" TRANSONIC TEST SECTION

The wind tunnel results would be extrapolated to full-scale and compared to the corrected flight test data using current methods. In addition, the wind tunnel and flight test results and model and airplane geometries would be published to serve as calibration cases for the development of improved prediction methods.

This program would be pursued by government agencies with support from industry in terms of airplane and wind tunnel model leasing agreements. Industry participation only is included in the recommended funding below.

Cost and Schedule

The flight/wind tunnel correlation program is estimated to cost approximately \$1.8 million and require approximately 1.5 years to complete. The recommended program is summarized in figure 55.

Roughness and Excrescence Drag

Potential Payoff

The objective of this program is to determine the drag-rise characteristics of individual roughness elements at near-sonic Mach numbers, and to define the influence of distributed roughness on the characteristics of supercritical airfoil sections operating near their design point. The current uncertainty in excrescence and roughness drag estimation for a near-sonic transport is equivalent to a direct operating cost increment of 1 to 2%. The payoff would be the definition of allowable excrescences and roughness tolerances compatible with aerodynamic efficiency and manufacturing costs.

State-of-Readiness

The drag of individual excrescences and distributed roughnesses is reasonably well established for subsonic and supersonic cruise airplanes. Much experimental testing, both in the wind tunnel and in flight test, has been done to measure the drag of roughness items such as rivet heads, skin splices, rough paint, etc. The drag of typical excrescences and protuberances has also been measured at subsonic speeds and cataloged for the use of airplane designers. Relatively little of this type of work has been done at transonic speeds; in addition, the drag sensitivity of supercritical airfoils to the influence of distributed roughness has not been established.

The subsonic roughness and excrescence drag level, expressed as a fraction of total airplane wetted-area-dependent drag, is shown in the upper portion of figure 56 for a number of large airplanes. The level assumed for this airplane study is also referenced in this figure. However, these values may not be applicable at near-sonic speeds. The variation of some typical excrescence drags with Mach number, taken from NASA data, are shown in the two plots at the bottom of figure 56. This sort of drag-rise due to roughness shows essentially a doubling of the subcritical drag level at $M = 1.0$ and would force extreme smoothness requirements upon a near-sonic cruise airplane. More experimental data are needed to establish what roughness drag-rise is reasonable and/or compatible with manufacturing costs on a near-sonic transport.

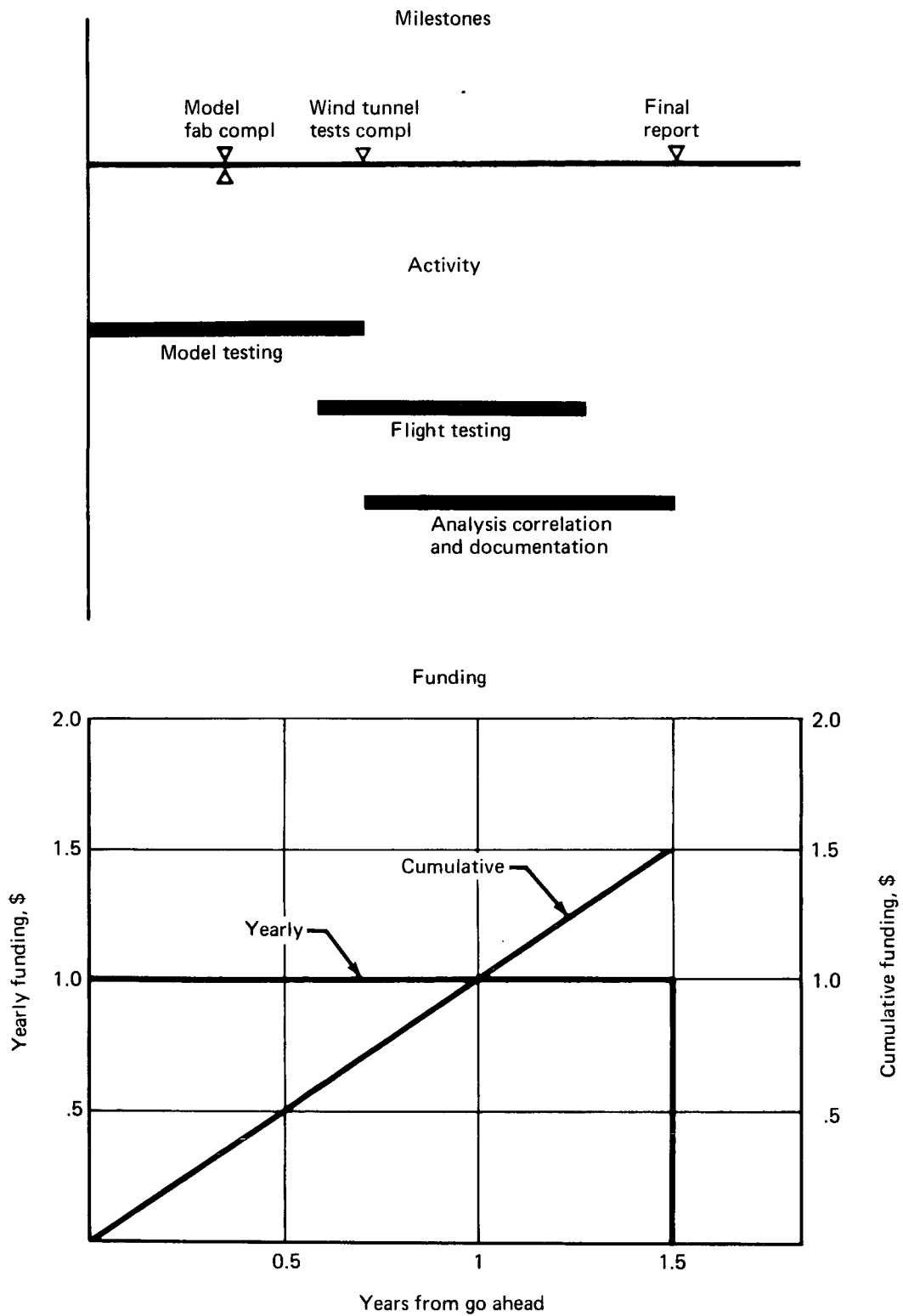


FIGURE 55.—FLIGHT/WIND TUNNEL CORRELATION FUNDING SCHEDULE

ONE HALF CENTIMETER
NO. 006 V (30 BY 40 DIVISIONS)

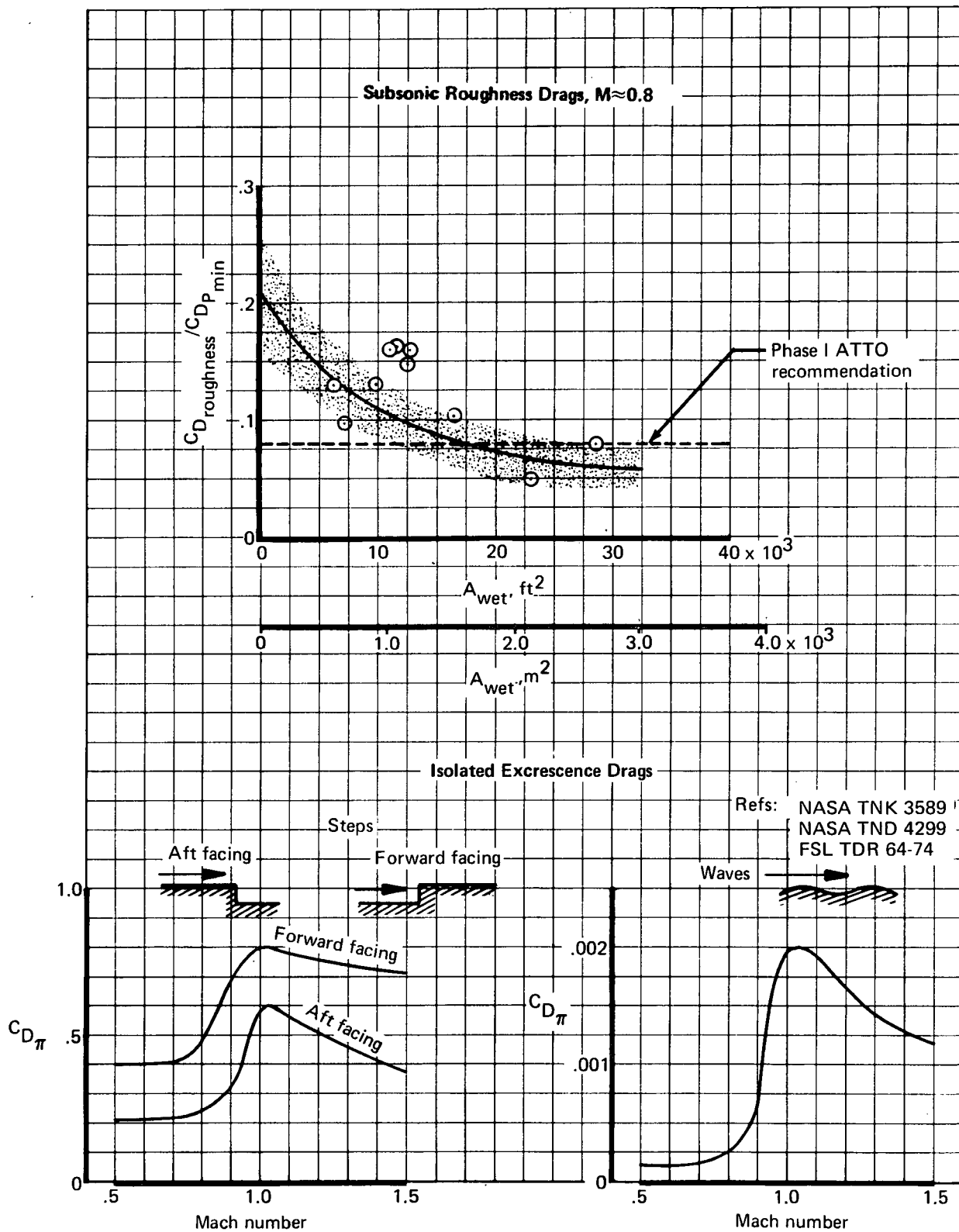


FIGURE 56.—

Recommended Action

A wind tunnel/flight test program for investigating the effects of roughness and excrescence at near-sonic speeds is recommended to obtain:

- Basic drag-rise data on the effect of typical roughnesses and excrescences near $M = 1.0$.
- The effect of distributed roughness on supercritical airfoil characteristics and critical Mach number.

The basic drag-rise data would be measured for a range of Reynolds numbers and excrescence height/boundary layer depth variables. Excrescences would include items such as sensor radomes, blade antennas, anticollision lights, and typical mechanism fairings.

The airfoil sensitivity to typical manufacturing roughnesses would be tested by means of replaceable-type roughness inserts in a supercritical airfoil section. Testing would be done in a high Reynolds number facility, using as large a model as practical. Roughness items would include leading edge device gaps, skin joint mismatches, rivet rows, etc.

The flight test program would be required to obtain "full-scale" correlation checks on the wind tunnel data. The test airplane would be the NASA F8 with the supercritical wing. Typical roughness and excrescence items would be added to the wing and body to measure their effect on drag-rise and critical Mach number.

Cost and Schedule

The recommended program for measuring the drag-rise of roughness and excrescences is estimated to require approximately 1 year's time and cost about \$200,000; the flight test program, which would be conducted subsequently, would require a year also, and cost approximately \$400,000.

The recommended roughness and excrescence drag problem is summarized in figure 57.

Sonic Boom During Cruise Slightly Below Mach 1.0

Potential Payoff

During certain meteorological conditions it may be possible for attached shock waves on aircraft cruising at near-sonic speeds to propagate to the ground. The first objective of this program is to determine experimentally the possibility of producing shock waves at the ground during subsonic cruise by detailed analysis of sonic boom field test data. Some data are available for analysis but more tests would be very desirable. A second objective is to determine meteorological conditions most favorable for "subsonic" sonic boom and to estimate how frequently such conditions exist at cruise altitude on an operational basis. The payoffs would be an increased understanding of the factors affecting sonic boom propagation and the evolution of reliable boom avoidance techniques.

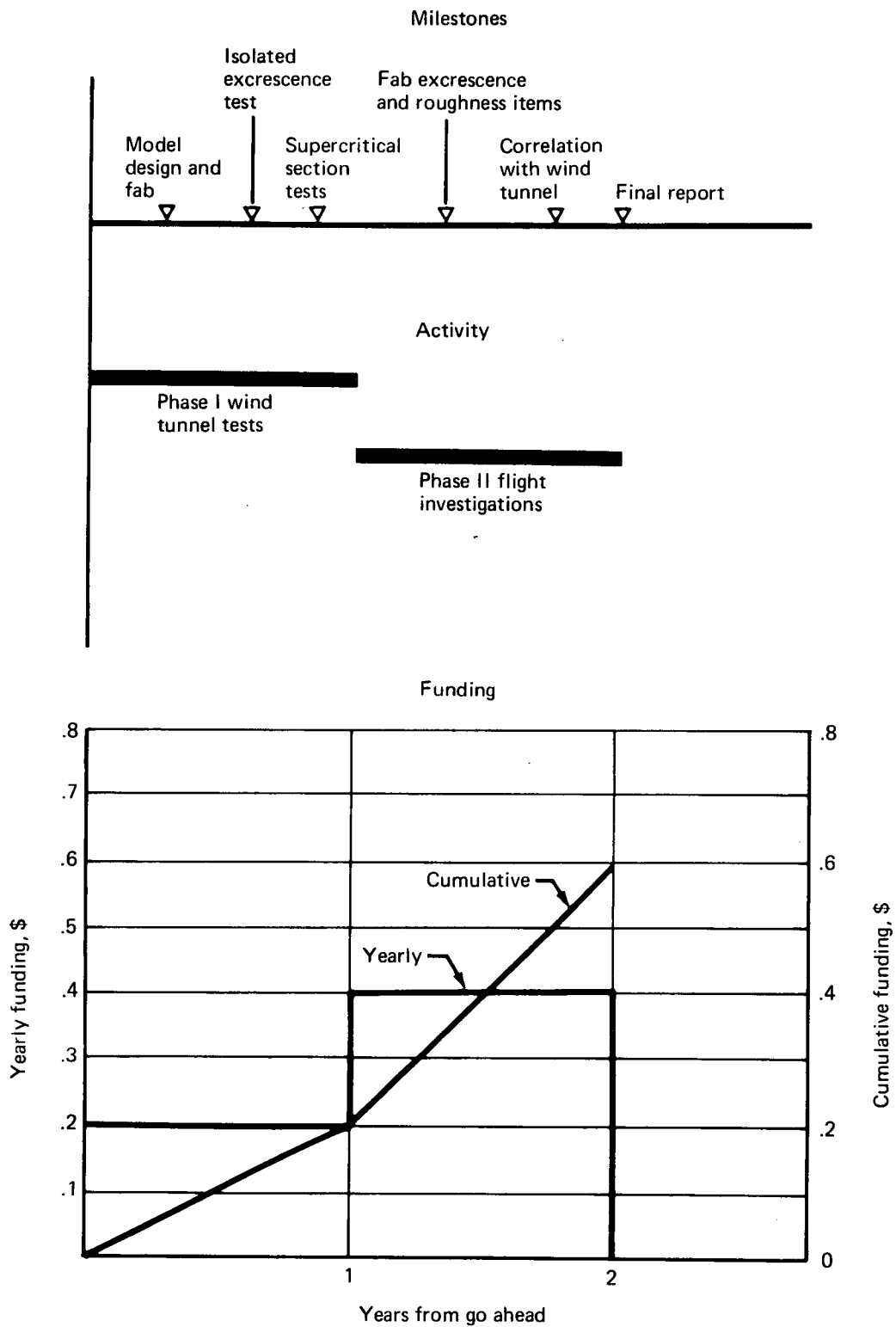


FIGURE 57.—ROUGHNESS AND EXCRESCENCE DRAG FUNDING SCHEDULE

State-of-Readiness

Some flight test data are available for analysis now. These data were obtained during the 1970 Jackass Flats sonic boom tests. Eleven flights were made at Mach numbers from 0.95 to 0.99 at 6000 feet altitude over the 1500-foot instrumented BREN tower. During three of these flights, sonic booms were observed on the tower and at the ground.

Additional flight tests designed specifically for this purpose would be very desirable. Use of the 1500-ft instrumented BREN tower at Jackass Flats is recommended, similar to the 1970 test series. Several months of planning is required.

Recommended Action

The currently available flight test data should be analyzed and, depending on the results of that analysis, additional flight tests would be scheduled. The analysis of available meteorological data for frequency of occurrence of subsonic sonic boom conditions should take place concurrently. A series of test flights would be planned to investigate the effect of such parameters as Mach number, airplane altitude, wind direction, and airplane configuration. Initial flights should be made using the NASA-modified F-8 airplane so that the effect of the supercritical wing can be determined.

Cost and Schedule

The study program would require about 18 months. During the first 6 to 8 months, the analysis of the available flight test data and planning of the additional flight tests would take place. The remainder of the period would be spent analyzing the additional flight test data and associated meteorological studies.

The recommended program for investigating sonic boom during cruise slightly below Mach 1.0 is summarized in figure 58.

STRUCTURES AND MATERIALS

During the course of the study, potential advances in Structures Technology were identified in the areas of materials and processes, load alleviation and improved design methodology as shown by figure 59. In order to evaluate the impact of these advances in Structures Technology, trade studies described in Volume I were conducted to determine their potential for a new technology transport aircraft.

Of the advanced structural material systems studies, bonded aluminum and composites offer the best weight savings and are cost-effective. Bonded aluminum is near term in its development; however, composites offer six times the potential weight savings. Composites will take six years longer and approximately \$110 million to develop basic technical data, and manufacturing processes and techniques. An additional estimated \$58 million would be required to conduct a recommended composite structure in-service evaluation program. A graphite composite material system shown to yield the largest weight savings at the lowest cost per pound for the systems studied.

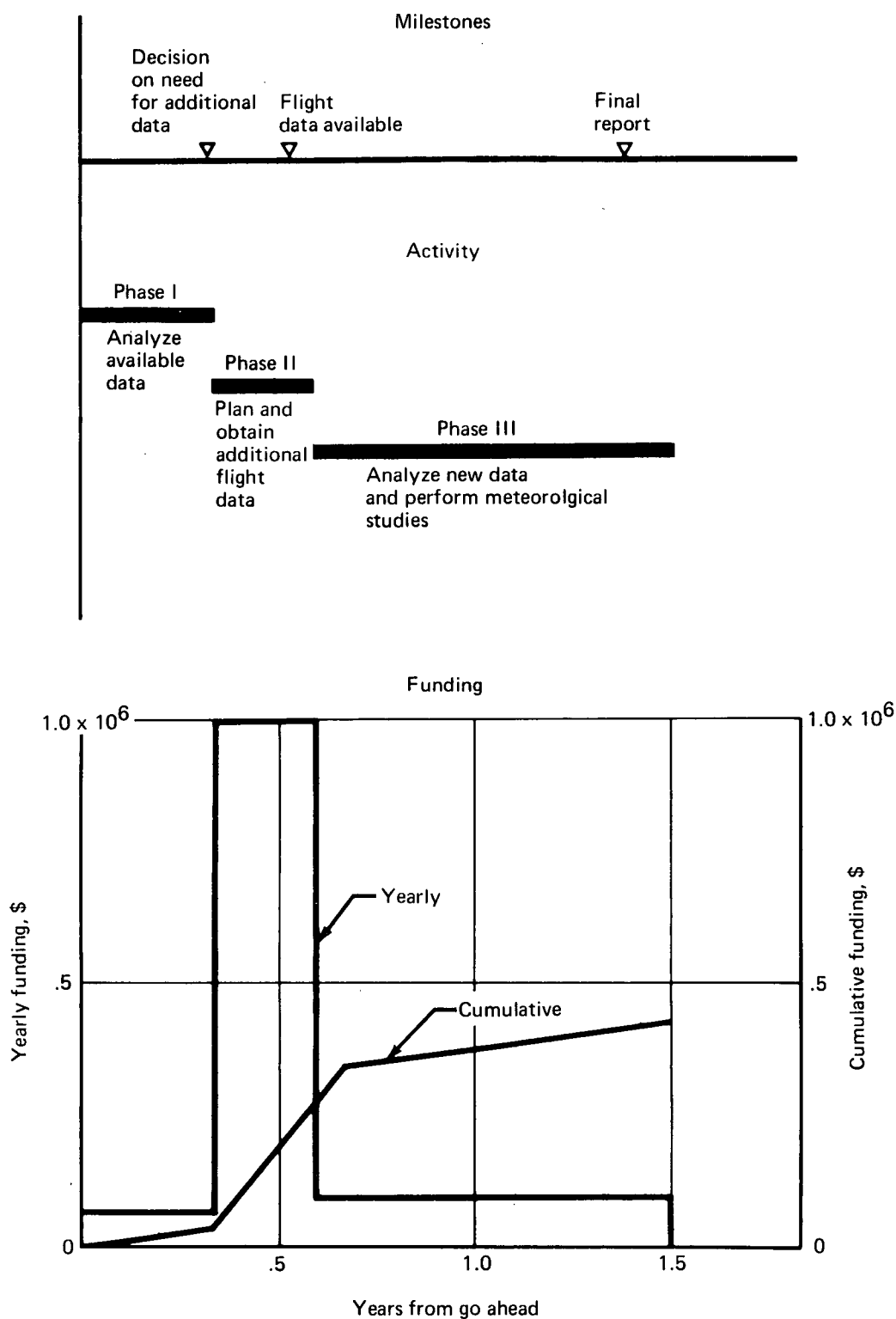


FIGURE 58.—SONIC BOOM DURING CRUISE SLIGHTLY BELOW MACH 1.0
FUNDING SCHEDULE

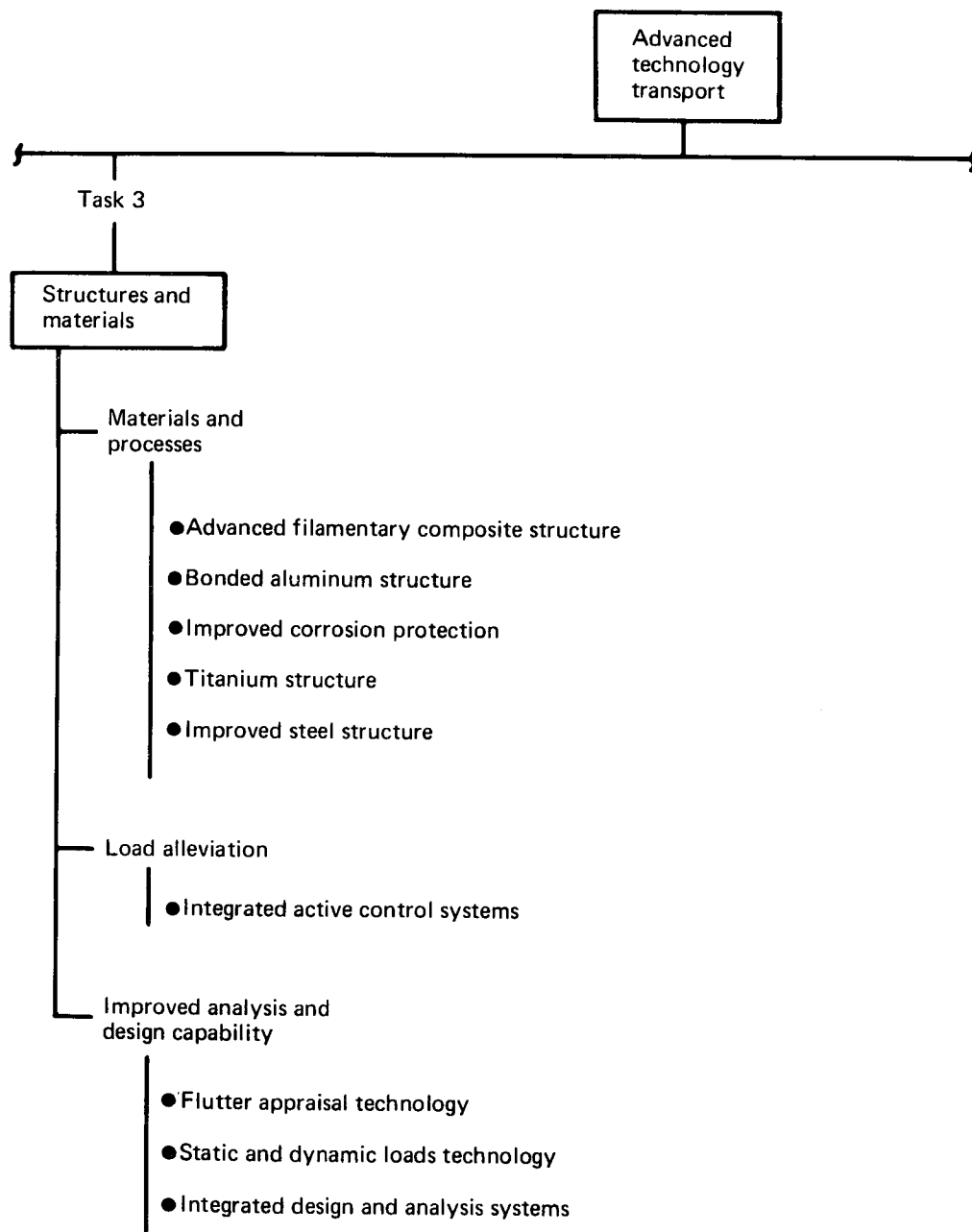


FIGURE 59.—STRUCTURES AND MATERIALS ADVANCE TECHNOLOGY PROGRAMS

Load alleviation was shown to be an effective way of saving weight at a reasonable cost per pound. The weight reducing effectiveness of flutter mode control is dependent on specific configuration characteristics and has a higher risk for incorporation than other load alleviation systems.

During the course of the studies, identification was made of design methodology advancements that would reduce the risk and evaluate the development of future advanced aircraft. These were:

- Study of the stiffness features of advanced composites material system and load alleviation to reduce the wing thickness ratio for reduced drag and engine thrust requirements.
- Study of the influence of orienting the filaments of composite material systems and how it may enhance the flutter weight penalty on flutter critical configurations.
- Study the application of advanced composites as a combined structural and acoustical system and what influence it has on nacelle thickness and aspect ratio, drag, noise attenuation, and weight.

The background and results of the trade studies are defined in Volume I while the potential payoff, state-of-readiness, and recommended actions are defined in the following paragraphs.

Advanced Filamentary Composite Structures

Boron and graphite fibers in epoxy matrices and PRD 49 were considered in this study. Boron or graphite composite use ranges from reinforcement for the conventional metal to primary structural material and was applied to most of the structure: wing, fuselage, landing gear, empennage and control surfaces. PRD 49 was used mainly for fairings and other secondary surfaces. Each advanced configuration was evaluated against the -611 structure for weight and operational cost differences.

Potential Payoff

Advanced filamentary composites have a potential payoff of great significance in commercial airplane primary structure. Composites also have potential applications in even broader commercial areas outside of the aircraft industry. Any strength or weight influenced product is a potential application. Transportation, architecture, furniture, even the textile and oil industries have possibilities for enormous payoff. This technology has the revolutionary potential of the transistor. These nonairplane applications can be stimulated by developments in the commercial airplane industry that make the technology available for use elsewhere.

The Commercial Composites Application Plan should be developed and implemented by NASA to ensure the early payoff of this technology. This plan would achieve two things:

- (1) The orderly development of commercial airplane primary structure applications, through monitoring and managing the Technology Development Program and its utilization in an In-Service evaluation program.

- (2) The planned implementation of rapid transfusion of this technology on an incremental basis into other industrial areas.

In commercial airplane applications, three levels of composite utilization are defined which represent an orderly transition from all-metal aircraft structure to all-composite structure. These three levels are identified as:

- Level 1 airplane operational in 1979
- Level 2 airplane operational in 1981
- Level 3 airplane operational in 1985

and are summarized in table 5.

Level 1 technology offers a potential weight savings of 5.5% of airplane structural weight for an airplane available for delivery in 1979. Boron or graphite fibers in an epoxy matrix have approximately twice the strength of aluminum, stiffness equalling that of steel and a density less than aluminum. The high stiffness-to-density ratio is particularly advantageous in wing structure where weight savings derived from increased strength need not be penalized by flutter stiffness requirements as often occurs with improved metal alloys.

Level 2 technology can be employed on an airplane available for delivery in 1981. Additional development of this material will permit reduction of airplane structural weight by 8.3%. In addition to retaining most of the Level 1 advantages, cross-ply reinforcement allows the tailoring of axial strength and stiffness in relation to shear strength and stiffness according to static or dynamic requirements. This is accomplished simply by adding more fibers in the direction of required strength or stiffness and allows a more efficient use of structural weight. The metal which is reinforced provides some strength and protects the composite from exposure to damage and weather.

Level 3 technology can be applied to an airplane available for delivery in 1985 to produce a reduction in structural weight of 19% relative to the baseline aluminum airplane. The use of all composite components in heavily loaded primary structure takes full advantage of lightweight, high strength fibers in large areas of sandwich as well as semimonocoque structure. Use of metal, with its lower strength and higher density can be held to a minimum at the Level 3 development stage. The ability to efficiently vary the quantity and direction of fibers in the composite will be highly developed.

The weight savings and cost benefits to be derived from this technology, applied to these three levels of airplane commitment, are conservatively summarized in table 5.

The real potential of this new technology will remain only potential unless it is truly proven. When applied to airplane primary structure, it must be durable enough to survive in the commercial airline operating environment. The In-Service Evaluation program is an orderly planned introduction of the technology in the commercial market. It will also produce the vital durability background required for full commitment.

TABLE 5. —ADVANCED FILAMENTARY COMPOSITE STRUCTURE

Technology*	Airplane availability date	Weight increment per airplane			% DOC change	Net present value of change (300 airplanes)
		lb mass	kg	% of structure		
Level 1	1979	-6600	-3000	-5.5	-1.3	\$83 000 000 increase
Level 2	1981	-9900	-4500	8.3	-2.5	\$181 000 000 increase
Level 3	1985	-22 600	-8900	-19.0	-5.5	\$380 000 000 increase

Level 1: Conventional structure plus :

- Primary structure
 - Reinforced with unidirectional boron/epoxy
- Secondary panels
 - PRD 49 fiber
- Secondary control surface:
 - All composite graphite/epoxy

Level 2: Level 1 plus:

- Primary structure
 - Reinforced with multidirectional boron/epoxy or graphite /epoxy
- Primary control surfaces
 - All composite graphite/epoxy

Level 3: Level 2 plus:

- Primary structure
 - All composite graphite/epoxy

State-of-Readiness

Progress in filamentary composite design and application has been promising in many directions. This section will present the accomplishments as well as the identified deficiencies as they appear in three areas:

- Commercial Composite Application Plan
- Material Technology Development
- In-Service Evaluation

Figure 60 presents these areas and the time-phased activity, past and planned, as identified by this study.

- **Commercial Composite Application Plan**
Filamentary composites have progressed from the research stage through initial technical development in a very short period, largely as a result of funding by the military. Military technology development and applications have shown that composites are an effective way to reduce weight and retain producibility.

The application of composites as a structural system for commercial airplanes had been pursued with limited effort. As a result only a few components are now actually acquiring service experience and many technical performance characteristics are not identified. A comprehensive plan for introducing composite airframe components into airlines service is necessary to gain commercial aviation confidence that the system is environmentally durable. The plan would ensure the orderly introduction of composites into commercial aircraft primary and secondary structure and also provide the means for "spin-off" of composites into nonaviation commercial structures.

- **Materials Technology Development**
LEVEL 1—The most promising application philosophy for initial use of advanced composite material employs bonded unidirectional composite to reinforce stiffened sheet construction, where the stiffeners are riveted or adhesively bonded to the skin. This approach has been studied and developed through NASA Contract NAS1-8858, and through company-funded research. NASA Contract NAS1-9540 has funded the study of the design of the C-130 center wing box utilizing reinforcing concepts, and the fabrication of DC-8 empennage structure with composite reinforcement is currently being proposed. Since the reinforcement is adhesively bonded to the metal components, many of the developments required for improvement of bonded metal structure are required for composite reinforcing. However, deficiencies exist in many areas:
 - **Design and Analysis:**
Joint design, ply drop-off, static analysis, fatigue life prediction, creep analysis of adhesives, optimum sizing of fail-safe straps, electrical charge dissipation.

- **Materials:**
Data for selection of fiber material and adhesive.
- **Design Data:**
Structural allowables, correct allowables test methods, structural element allowables, allowables reduction for defects.
- **Manufacturing:**
Automated tape layup machine, production of structural shapes, adhesive bonding of tapes, disposal of toxic wastes, integration of total plant process, control of residual thermal stresses.
- **Quality Assurance and Damage Repair:**
Inspection techniques, nondestructive test methods, damage repair.
- **Component Verification:**
Confidence in full-size components.

LEVEL 2—A recent test, conducted in support of NASA Contract NAS1-8858, has demonstrated static strength capability of a composite reinforced window belt panel having three windows. Completion of the developmental programs required for Level 1 will resolve many questions relating to multidirectional reinforcement, but information will still be needed in many areas.

- **Design and Analysis:**
Joint design, ply drop-off, design of curved panels with cutouts, static analysis of reinforced skins, fatigue analysis of reinforced skins, crack propagation and damage containment.
- **Design Data:**
Allowables for flat and curved panels, effects of defects on allowables.
- **Manufacturing:**
Application of cross-ply reinforcement to compound contoured skins, control of residual thermal stresses.
- **Quality Assurance and Damage Repair:**
Equipment definition, cross-ply reinforcement repair methods.
- **Component Verification:**
Confidence of applicability of above development to full-size components.

LEVEL 3—Developmental programs for multidirectional composite construction have been conducted primarily through Air Force contract and have, therefore, used military airplane components. The use of boron composite has been studied for the T-39 wing box and the wing skins of the F-100. Boron composite is also being used for the C-5A wing leading edge slat and developed for the fuselage and empennage structure of the F-111. A rudder has been developed for the F-4 using

composite construction as have numerous components for the F-5. A study that began the investigation of the dissipation of static electricity and lightning strikes was done under Air Force contracts F33615-69-C-1612 and F33615-71-C-1198. This study and that recommended in Level 1 applies to secondary structure, but would not include the development required for all-composite primary structure.

Due to the size of the technology increment required to implement multidirectional composite construction, many unknowns relative to their application to commercial transports exist at this time. An example of this is the generation of structural allowable stresses. An unlimited number of combinations of ply or lamina orientations are possible in multidirectional composite construction. Developing allowable stress data for all possible combinations is impractical and so some new allowable stress philosophy may be required. Similarly, a large number of manufacturing methods remain to be explored. The methods which ultimately are adopted for cost-effective construction are dependent upon the component configurations. Further requirements thereafter are categorized under the general headings:

1. Application studies
 2. Conceptual hardware
 3. Material system development
 4. Manufacturing feasibility hardware
 5. Production development
 6. Verification hardware
- In-Service Evaluation
A complete component development program for design, manufacturing, and in-service experience leading to qualified hardware would be required before extensive commitment to advanced filamentary composites in primary structure could occur. Such a program should be closely tied into Levels 1, 2, and 3 materials technology development and subject to modification depending on results of those development programs. Work underway that is closely related to the in-service evaluation program includes the following:
 - Foreflap:
Two 707 foreflaps developed with contractor funds have accumulated over 5000 hours of commercial airline service without incident. This application of composite employs multidirectional boron/epoxy skins bonded to flexcore aluminum honeycomb.
 - Spoiler:
Two 737 spoilers developed with contractor funds have recently entered commercial airline service. The contractor has proposed that NASA fund an expanded in-service evaluation program with 114 spoilers in service with five airlines. This application of composite employs multidirectional graphite/epoxy skins bonded to full-depth aluminum honeycomb core.

- **Body:**
Under Contract NAS1-11162, the contractor is presently evaluating major components of body primary structure for composite applications. Graphite/epoxy is being considered for both conventional and honeycomb sandwich body shell components in unidirectional and multidirectional applications.

The in-service evaluation program can be extended to the remaining items on figure 60 to cover cargo doors, nacelles, body and wing box. The ATT Program has shown the wing inspar panels to be an attractive application of composites on commercial airplane structure.

Recommended Action

Composite structure is under various stages of development for many military and a few commercial airplane flight hardware items at this time. This work provides a firm technical base for application of composites to commercial airplanes. It does not automatically ensure the use of this material, whatever its advantages. Development of new concepts and materials in the past has proven very costly, and therefore, other new developments are viewed with a skepticism that is proportional to cost. Advances cannot be imposed on private industry. An orderly progression of acceptance is required.

To achieve the maximum effect of the advantages of these new materials in a timely manner, two things must happen.

- (1) The airframe contractor must be convinced that a viable product can be produced economically and be of such quality as to be warrantable for commercial airline operation.
- (2) The commercial airlines customer must be convinced that this new product is so advantageous that it is worth buying.

When this has occurred, composite structure will find commercial acceptance on its own merit. The in-service evaluation program, based on the technology development program and implemented by the commercial composite application plan, will achieve this objective.

- **Commercial Composite Application Plan**
The contractor recommends that NASA fund a program to be conducted by an airframe manufacturer which will include the following activities:
 - **Design/Technology Appraisal:**
 1. Survey and monitoring of filamentary composite material/manufacturing technology advances.
 2. Analysis of material availability and requirements.
 - **Agency/Airline/Manufacturer Coordination:**
 1. Coordination with FAA and other regulatory agencies to achieve specification compatibility.

YEARS FROM GO-AHEAD

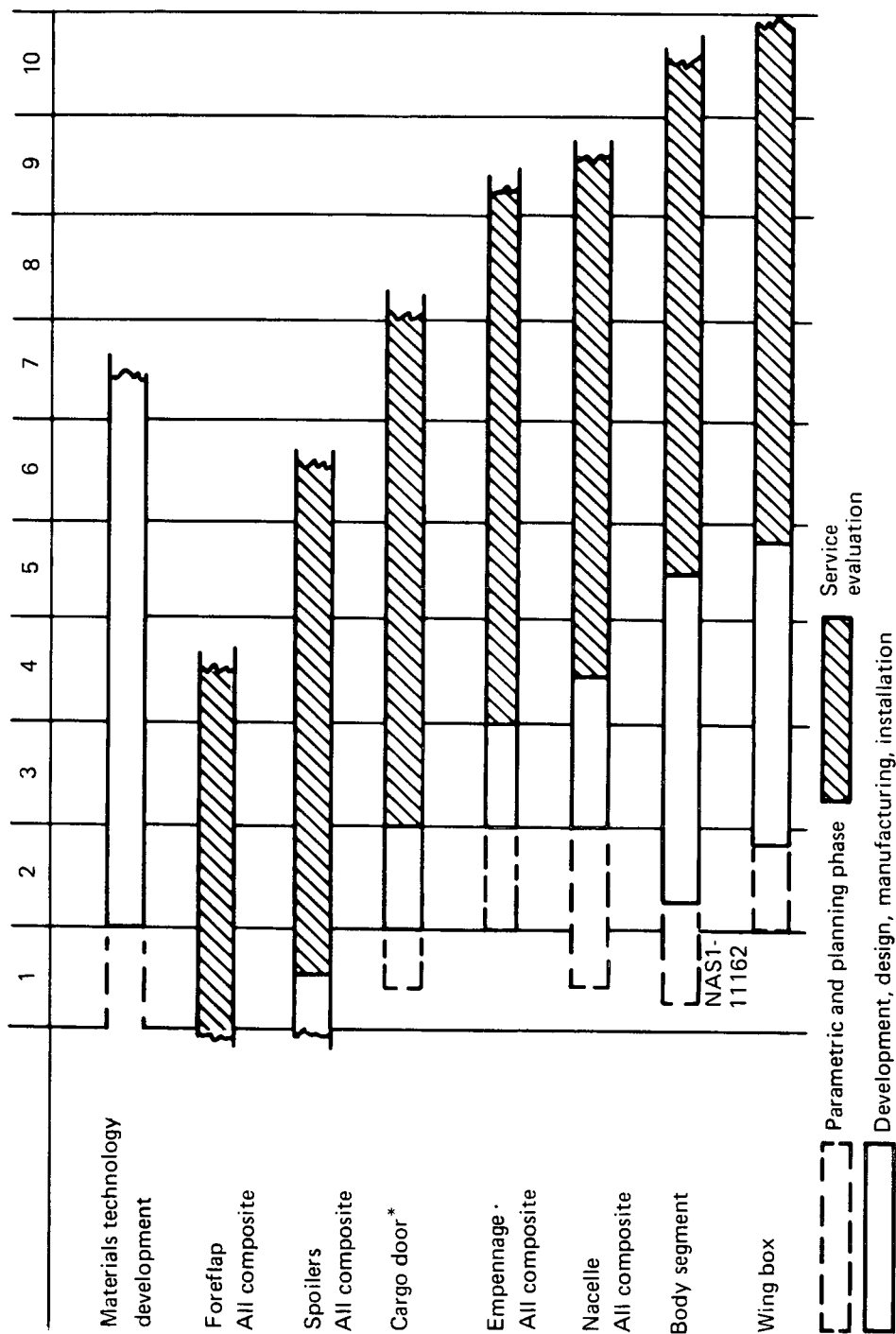


FIGURE 60.—COMMERCIAL AIRPLANE ADVANCED FILAMENTARY COMPOSITE DEVELOPMENT PROGRAM

2. Coordination with commercial airlines regarding composite applications and their related benefits and future requirements.
 3. Coordination with regard to commercial airframe manufacturers' composite activities.
 4. Monitoring and evaluation of in-service composite airframe structure.
- Industrial Spinoff:
 1. Active dissemination of technology fallout to industries outside of aerospace.
 2. Preparation of composite application proposals for new industrial applications.
 - Material Technology Development

Based on the technical deficiencies described in the preceding sections, development programs encompassing all technological disciplines are recommended. These programs, funded by NASA and conducted by an airframe manufacturer, are defined to permit orderly acquisition of the information to proceed successively from Level 1 to 2, and Level 3 technology applications as outlined below:

LEVEL 1

- Design and Analysis:
 - Joint Design—Fatigue-resistant joint design through design, analysis, and development and verification testing.
 - Ply Drop-Off—Ability to incorporate ply drop-off with adequate fatigue life through design analysis, and development and verification testing.
 - Static Analysis—Analysis capability for biaxially loaded and shear loaded reinforced members, conduct verification testing.
 - Fatigue Life Prediction—Methods of fatigue analysis of typical joints and defect discontinuities including thermal stress effects, conduct verification testing.
 - Creep Analysis of Adhesives—Survey existing theory, define parameters of interest and conduct verification testing on creep phenomena in connection with fiber termination during and after fabrication.
 - Optimum Sizing of Fail-Safe Straps—Determination of crack propagation as affected by cyclic frequency and environment as well as dynamic crack arrest capability.
 - Electrical Charge—Dissipation of static electricity and lightning strike in all-composite secondary structure.

- **Materials:**
 - Data for selection of fiber material and adhesive. Define minimum acceptable material characteristics; conduct screening tests; prepare material specifications for those selected.
- **Design Data:**
 - Structural allowables. Conduct allowables testing.
 - Correct allowables test methods. Proper methods for testing very stiff fibers in flexible matrix.
 - Structural element allowables. Extend range of allowables data to all metal shapes of interest for axial and combined loads by analysis and allowables testing.
 - Allowables reduction for defects. Analysis and testing of specimens with built-in defects.
- **Manufacturing:**
 - Automated tape layup machine. Develop first generation automated equipment.
 - Production of structural shapes. Develop specification for a first generation pultrusion machine, die materials and advanced curing methods for producing continuous lengths of structural shapes.
 - Adhesive bonding of tapes. Develop rapid but precise methods for bonding tapes to metal by use of prebonding spray system.
 - Disposal of toxic wastes. Develop procedures for reclamation and disposal of wastes from prebonding spray system.
 - Integration of total plant process. Develop integration of prebond spray process into other processes by use of computer control.
 - Control of residual thermal stresses. Continued development of manufacturing techniques by analysis and test verification.
- **Quality Assurance and Damage Repair:**
 - Inspection techniques. Define critical processing parameters in fabrication and develop techniques to monitor and measure those parameters.
 - Nondestructive test methods. Fabricate, inspect and structurally test selected components to develop techniques and relate readings to flaw severity.
 - Damage repair. Design, analysis and testing to provide repair processes for representative damage and defects.

- Component Verification:
 - Confidence in full-size components. Conduct tests on full-size airplane components to demonstrate airworthiness, weight improvement and verify manufacturing costs indicated by the results of the programs outlined above.

LEVEL 2

- Design and Analysis:
 - Joint design. Analysis and verification testing to develop sound joint configurations to meet static strength and fatigue requirements.
 - Ply drop-off. Analysis and developmental testing to develop ply drop-off practices which result in sufficient strength and fatigue life.
 - Design of curved panels with cutouts. Analysis and verification testing to develop sound design practices.
 - Static analysis of reinforced skins. Extension of finite element analysis programs to provide this capability and verification of results by static testing.
 - Fatigue analysis of reinforced skins. Develop fatigue life prediction capability to include reinforced structure subjected to shear, axial and combined load; verification testing of resulting methods.
 - Crack propagation and damage containment. Extend this analysis capability to reinforced skins and verify by testing.
- Design Data:
 - Allowables for flat and curved panels. Allowables testing of flat and curved panels subjected to shear, axial and combined loads.
 - Effects of defects on allowables. Allowables testing of cross-ply reinforced structure with selected sizes and shapes of built-in defects.
- Manufacturing:
 - Application of cross-ply reinforcement to compound contoured skins. Develop production methods.
 - Control of residual thermal stresses. Study problems; define suitable manufacturing techniques and evaluate them through fabrication and testing of representative parts.

- Quality Assurance and Damage Repair:
 - Equipment definition. Develop equipment specifications necessary to handle increased quantity of inspection.
 - Cross-ply reinforcement repair methods. Develop processes for repair of cross-ply reinforced structure.
- Component Verification:
 - Confidence of applicability of above development to full-size components. Conduct tests on selected full-size airplane components to demonstrate airworthiness, weight improvement and verify projected manufacturing costs.

LEVEL 3

- Application:

An initial application study phase is recommended to identify the potential product application. Weight estimates would be prepared to provide justification for the follow-on programs and the total program length and level of effort would be established to meet the desired design go-ahead goal. Structural criteria and material requirements would be established and structural concepts defined to permit assessment of weight savings and cost effectiveness.
- Conceptual:

During Phase II the structural concepts identified in Phase I would be developed and moderate size test panels demonstrating these concepts would be manufactured. These panels would be used to identify material processing, manufacturing, and quality control problems which were not foreseen in Phase I. The design and analysis methods used would be verified through tests conducted using this conceptual hardware. This phase would provide information required to complete the detail planning for subsequent phases.
- Material System Development:

Final material system requirements would be defined and accomplished during the third phase of the developmental program. Material and process specification would be prepared and selected materials qualified through test programs. This phase would pace the fabrication of follow-on test hardware and specimens required for allowable stress testing, but could be a relatively small effort if composite reinforced construction is developed prior to this effort to develop multidirectional composite construction.
- Manufacturing Feasibility Hardware:

The objective of the fourth phase of the program would be to develop any required allowable stress data and to produce feasibility hardware representative of production size primary structure. Manufacturing feasibility would be demonstrated for both basic panels and for areas having unique problems such as joints, major cutouts, and areas where large concentrated loads are introduced.

Hardware produced during this phase would permit manufacturing to examine competitive production processes and make selections based on actual hardware while static and fatigue testing of these components would verify design and analysis techniques.

- **Production Development:**

The fifth phase would involve the remaining effort still required to support the production application. This would include a review of the concept feasibility and the material system selections. The allowables program would be completed. Studies would be conducted to establish tooling, manpower skills, and facilities requirements. Cost estimates and program timing aspects would be reviewed.

- **Verification Hardware:**

The verification hardware phase would include the design, analysis, and fabrication of full-scale components for subsequent static, fatigue and flight test evaluations. Inspection techniques to assure product quality would be demonstrated as well as electrodynamic system compatibility. Strain surveys would be performed to verify analysis techniques. Included also would be the definition of repair techniques required for both shop and field repairs.

- **In-Service Evaluation:**

A proposed in-service evaluation program is necessary before extensive commitment to composites in commercial airplane primary structure. The recommended program follows:

Foreflap: No further action by NASA is recommended on this item.

Spoiler: It is recommended that this program be expanded under NASA contract as to cover 114 spoilers in service with five airlines.

Cargo door: An in-service evaluation of six cargo doors and associated qualification hardware is recommended.

Empennage: It is recommended that NASA fund a program to provide in-service evaluation of all-composite empennage primary structure. Such a program should include components for at least six commercial airplanes.

Quiet/structural nacelle: It is recommended that NASA fund a program to include in-service evaluation of six nacelles on a three-airplane fleet, in commercial operation. This would also include hardware required for flight certification, including structural and fatigue tests.

Body: Under Contract NAS1-11162, the contractor is presently evaluating major components of body structure for various concepts of composite applications. It is recommended that NASA fund an in-service evaluation program of flight articles on 10 airplanes, as well as hardware required for flight qualification and certification.

Wing box: This item, which has such great potential for improving commercial airframe structural weight, also poses the most serious risk potential. The wing box in-service evaluation program is a most vital step towards acceptance and qualification of composites on commercial airplanes. The contractor strongly recommends that NASA fund an in-service evaluation program. This program should be conducted by an airframe contractor and should include 10 airplanes in commercial airline operation, as well as the necessary structural and fatigue test components.

Cost and Schedule

Figure 61 shows the scope of events and costs foreseen for the development of a Commercial Composite Application Plan. Periodic tailoring of the plan will allow reassessment of content and funding.

The acquisition of the technology required to produce an airplane employing Level 1 unidirectional composite reinforcement is estimated to be \$26.1 million. This expenditure occurs over a 5-year period (see figure 62). The addition of Level 2 cross-ply reinforcement technology, figure 63, requires an expenditure of \$31.5 million in addition to the Level 1 cost, bringing the total cost of combined Level 1 and Level 2 technology to \$57.6 million. Level 3 technology, figure 64, requires funding totaling \$52.5 million over a 7-year-time span. The total cost to acquire multidirectional composite technology for primary and secondary structure is \$110.1 million when the cost of Levels 1 and 2 technologies is included. A summary of the total material technology costs is shown in figure 65.

A preliminary estimate of costs and scheduling to acquire the in-service evaluation experience has been developed and shown in figure 66. The total costs are presented in a range to account for the many variables, such as number of flight specimens and specific configurations which remain to be established.

For visibility of the total program, figure 67 shows funding for each of the three composite program elements and their cumulative amount.

Bonded Aluminum Structure

The potential of applying bonded structural concepts to primary airframe structure was studied. The major objective was to determine the structural advantages of this concept and examine the cost and developmental activities required for production implementation.

Potential Payoff

Bonding can be used as an effective way of fastening metal structure. Its principle advantages are in the elimination of load concentrating fasteners and improved material allowables in a structural system application.

The airframe areas immediately identifiable as candidate bonded structure are the fuselage and wing structure. Fuselage studies indicated adhesive bonded aluminum honeycomb sandwich is an efficient structural material. Fuselage weight savings of 2.9% of total airplane structure were indicated at no increase in cost.

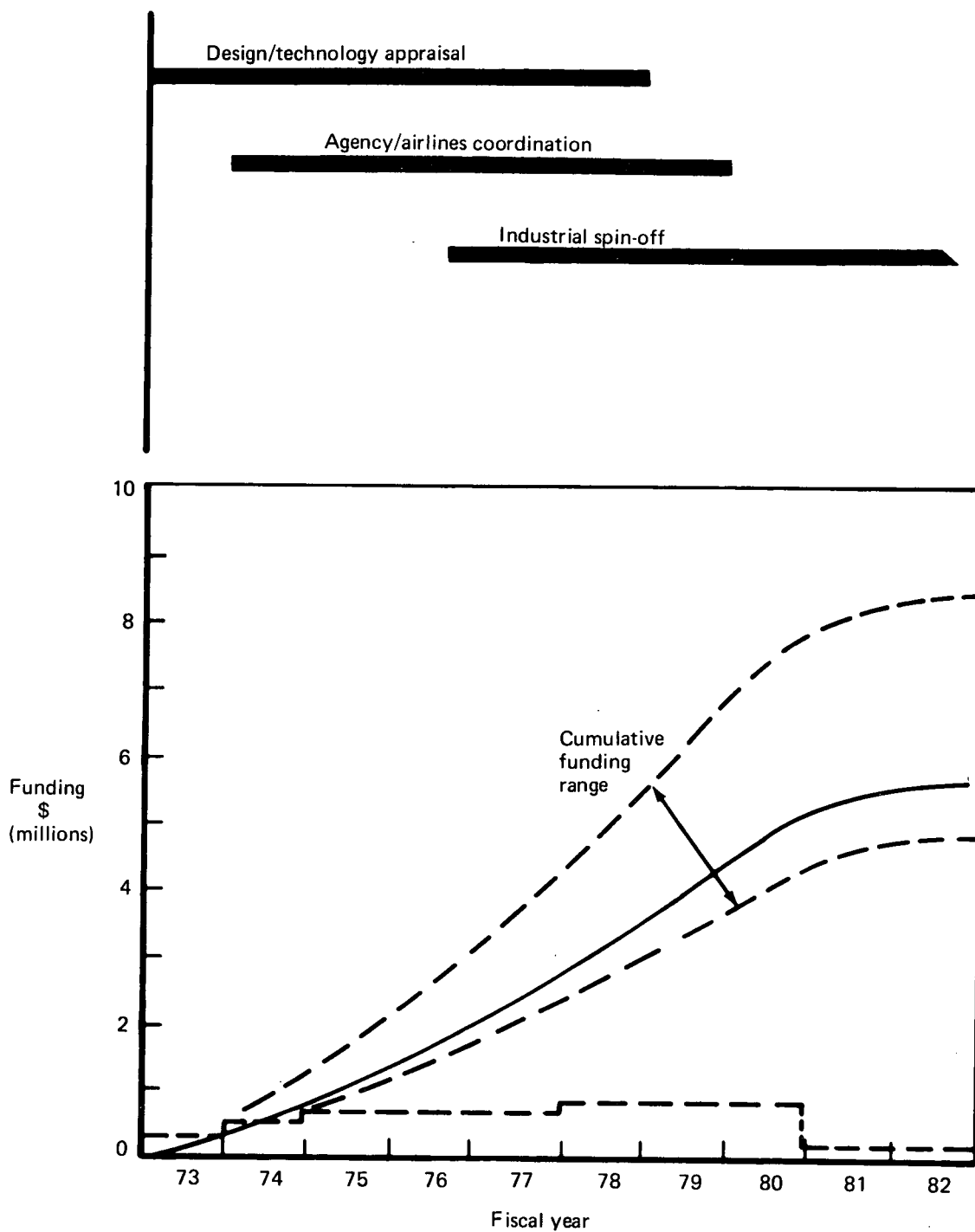


FIGURE 61.—SCHEDULE AND COST—COMMERCIAL COMPOSITE APPLICATION PLAN

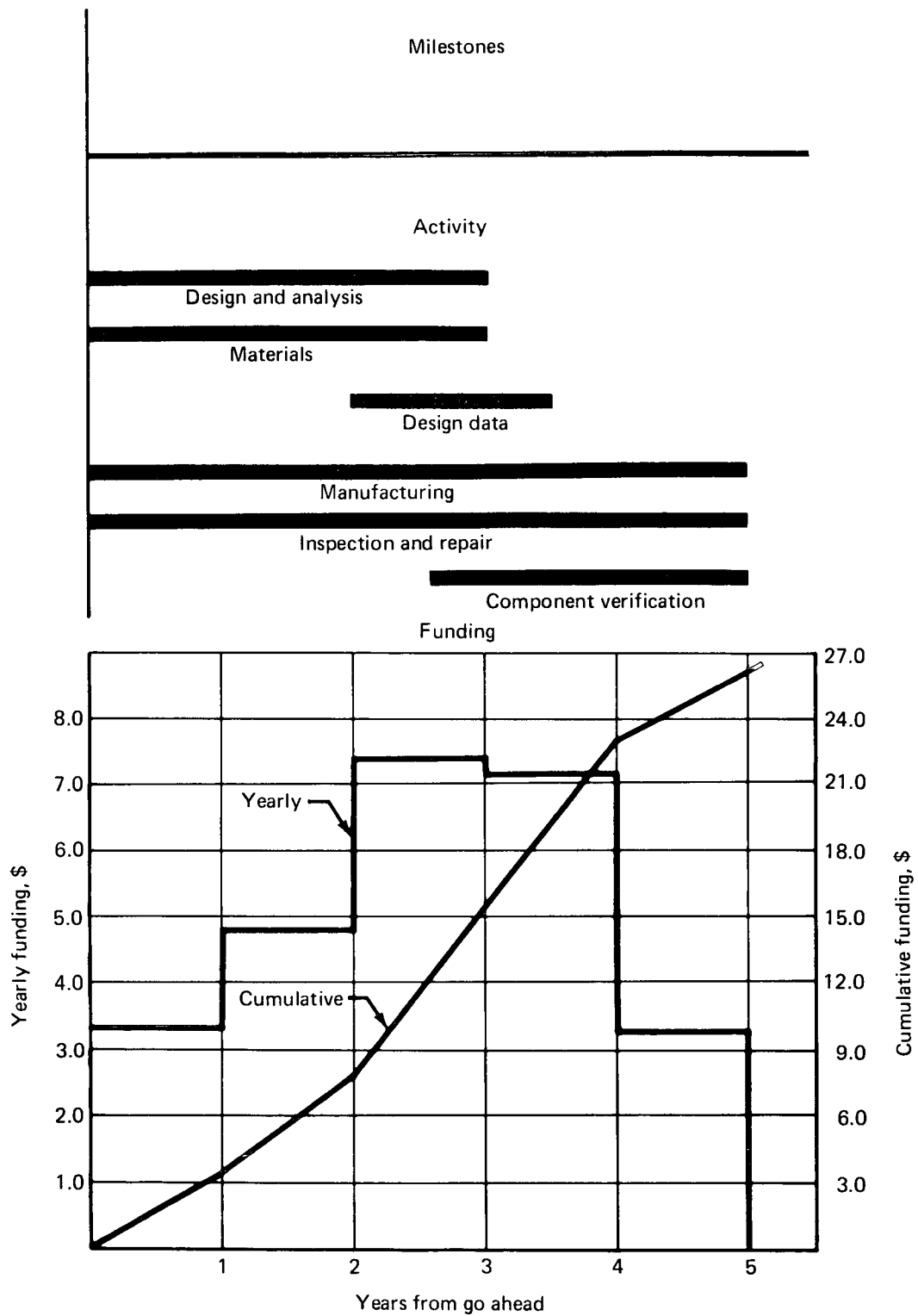


FIGURE 62.—DEVELOPMENT OF ADVANCED FILAMENTARY COMPOSITE STRUCTURE (LEVEL 1) FUNDING SCHEDULE

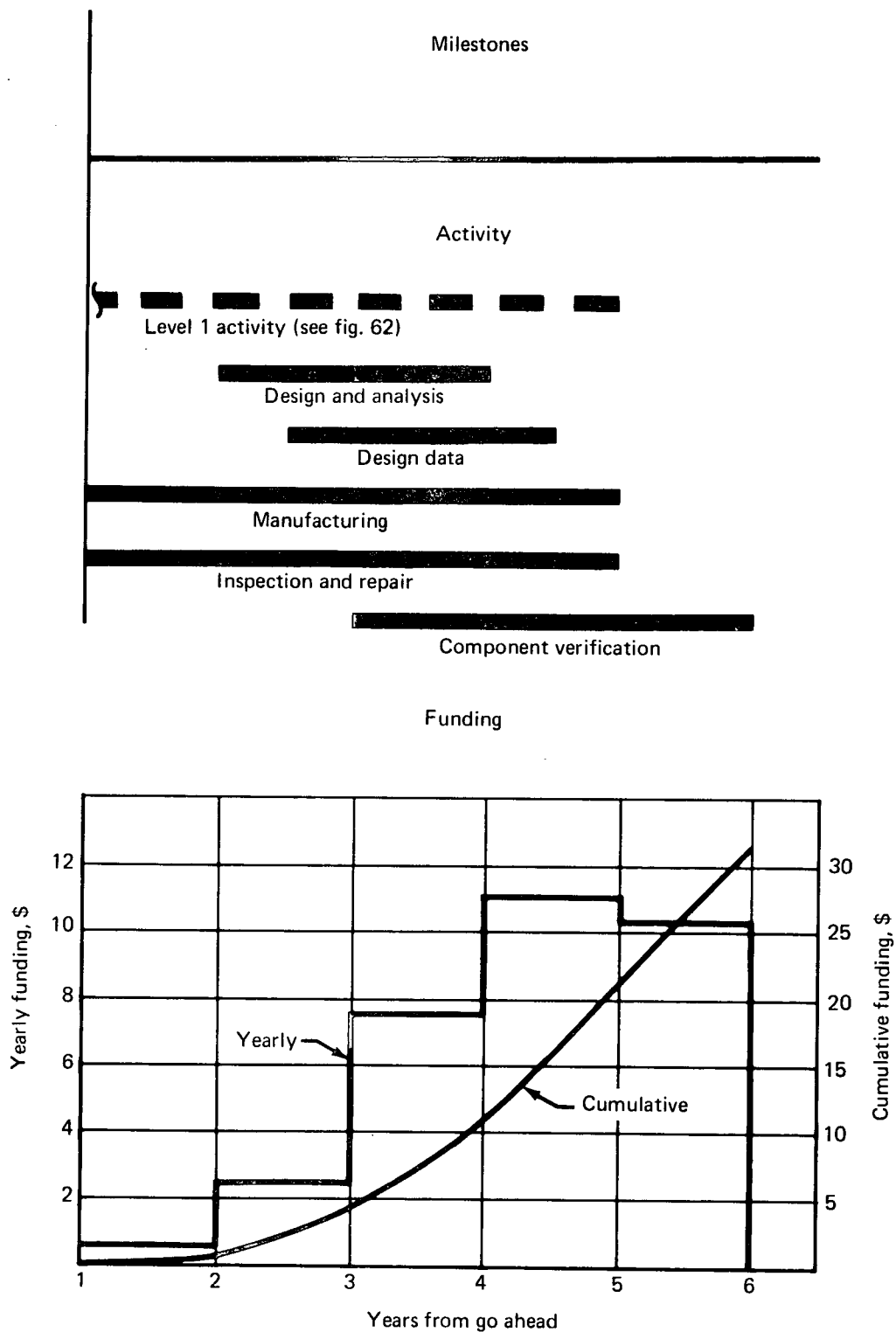


FIGURE 63.—DEVELOPMENT OF ADVANCED FILAMENTARY COMPOSITE STRUCTURE (LEVEL 2) FUNDING SCHEDULE

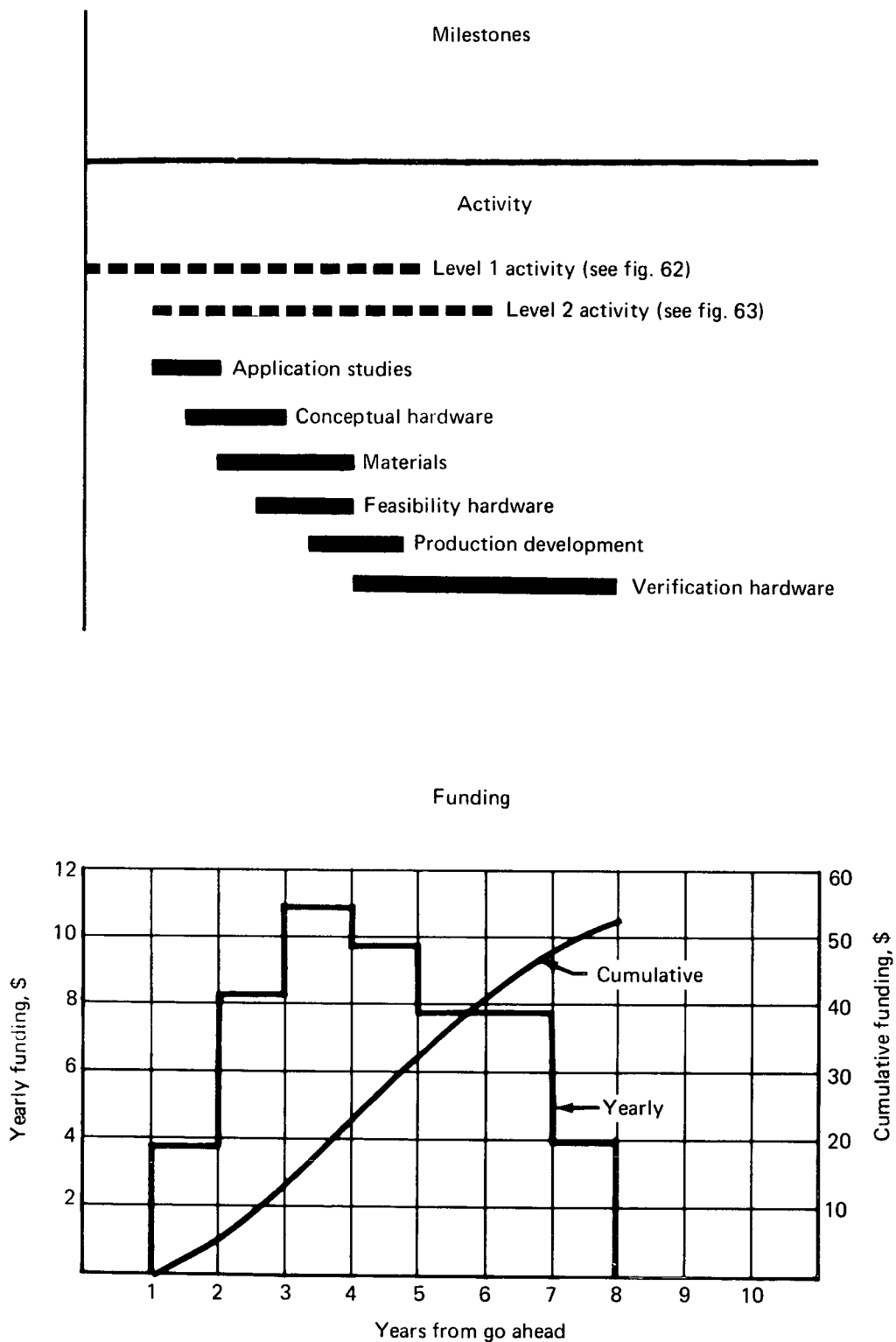


FIGURE 64.—DEVELOPMENT OF ADVANCED FILAMENTARY COMPOSITE STRUCTURE (LEVEL 3) FUNDING SCHEDULE

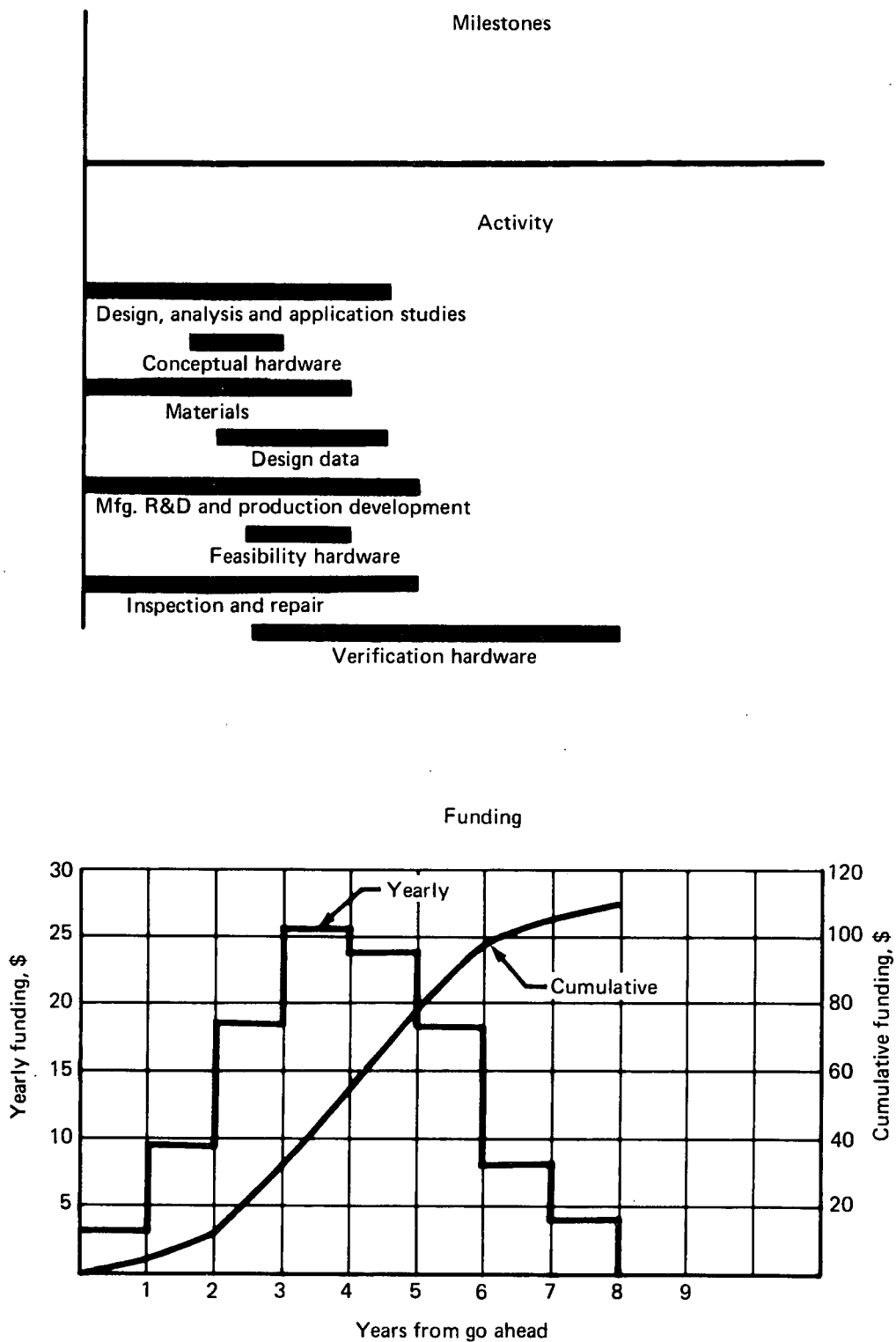


FIGURE 65.—DEVELOPMENT OF ADVANCED FILAMENTARY COMPOSITE STRUCTURE (TOTAL FOR LEVELS 1, 2, AND 3) FUNDING SCHEDULE

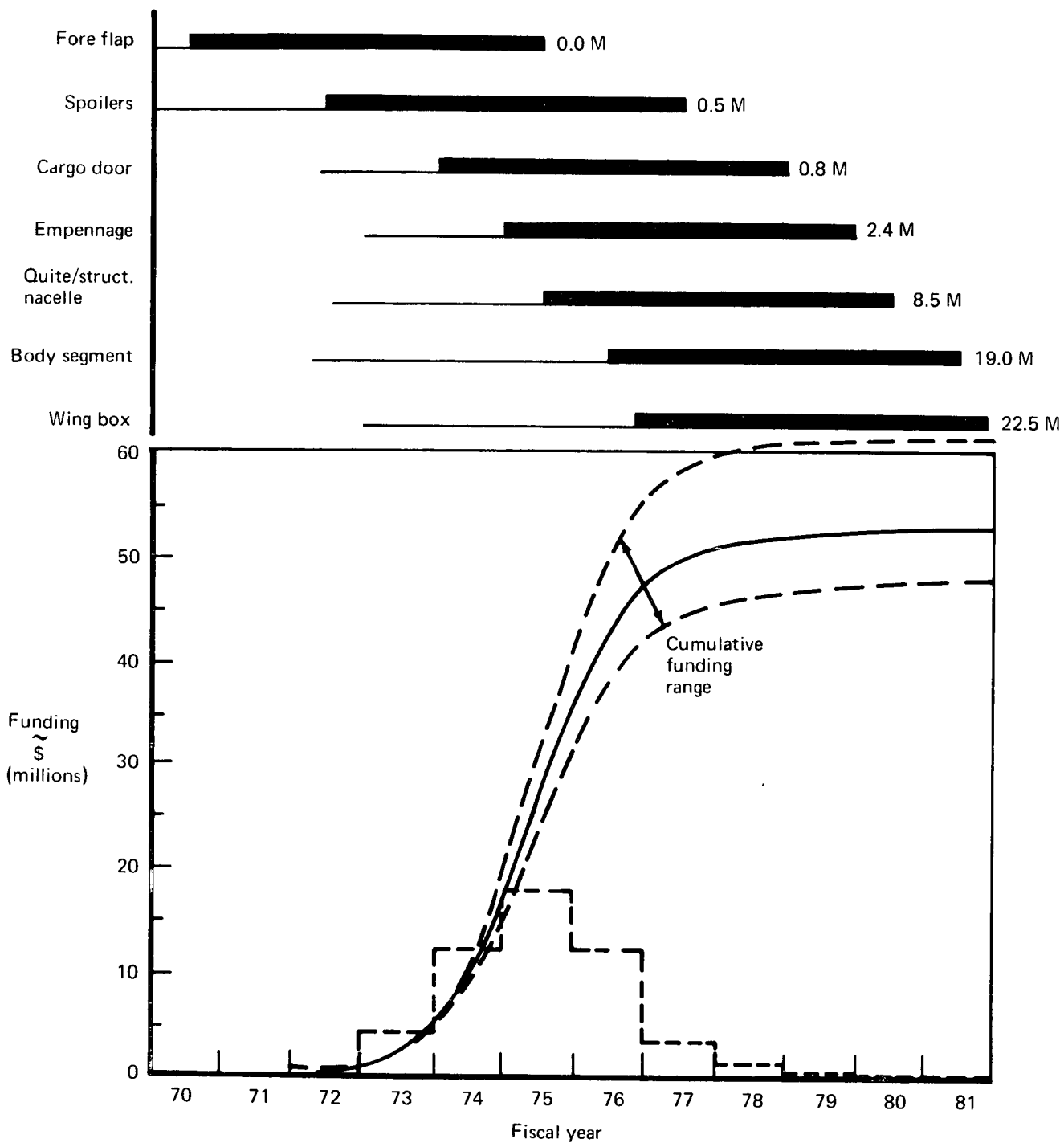


FIGURE 66.—SCHEDULE AND COST—IN-SERVICE
EVALUATION FILAMENTARY COMPOSITES

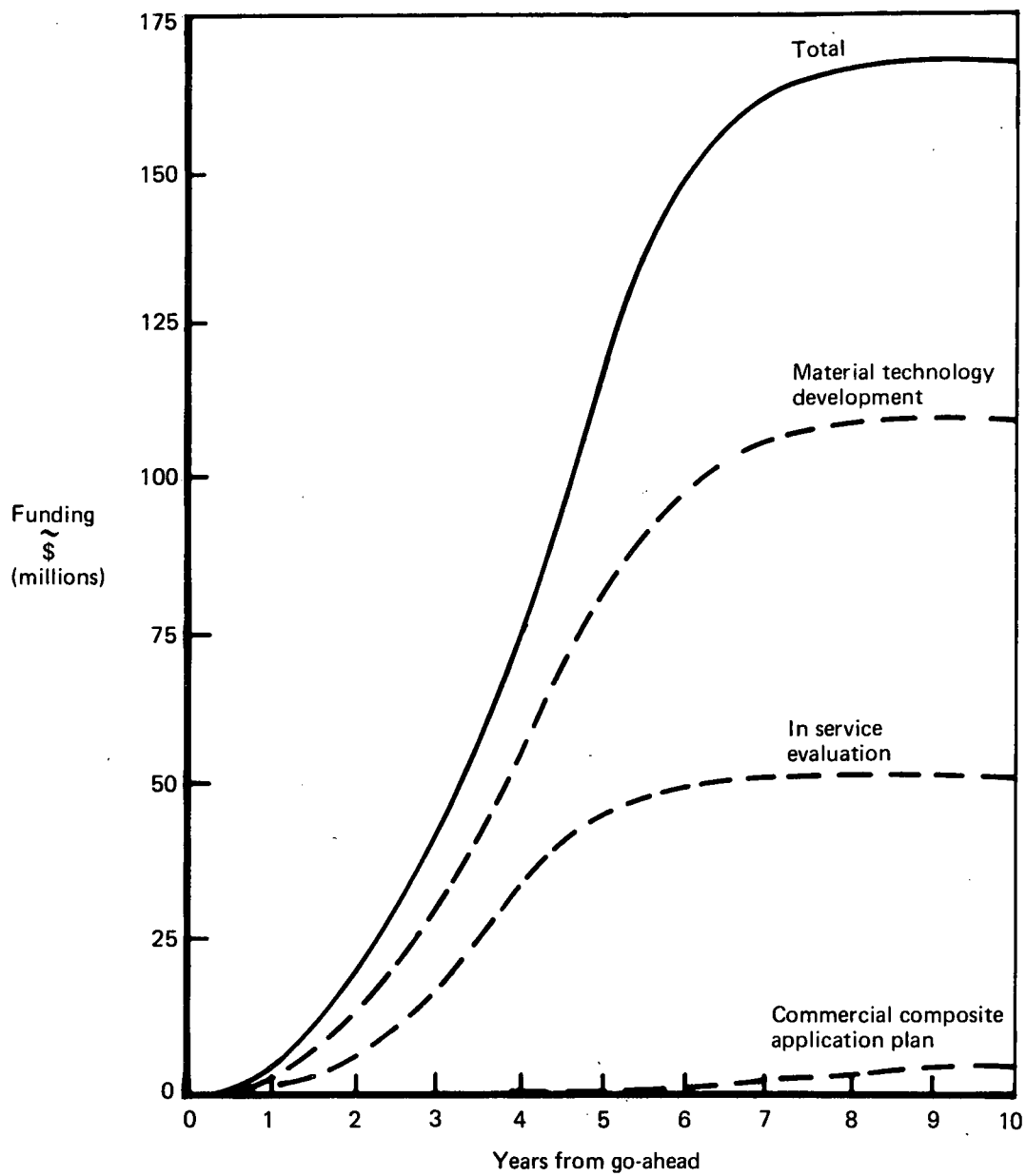


FIGURE 67.—SCHEDULE AND COST—SUMMARY—
ADVANCED FILAMENTARY COMPOSITE STRUCTURES

3

Wing studies indicated a bonded skin-stringer lower surface configuration is an efficient design. The bonded skin-stiffener wing structure realizes its main design advantage by offering load-carrying material that is not compromised by the stress concentrations of rivet and bolt holes. Allowable stress levels in tension-critical structure can be increased by as much as 7%. Weight and cost results of the wing study yield the unusual combinations of 800 lb (363 kg) per airplane (0.79%) weight saving and a cost saving amount to \$72/lb (\$159/kg) of weight saved (resulting from elimination of a large number of fasteners). Study results are summarized in table 6.

Current State-of-Readiness

Adhesive bonded primary structure is an achievable goal for commercial aircraft in the late 1970s. There are several areas requiring additional investigation before a firm commitment may be made for an effective, low-risk end item. U.S. aircraft manufacturers have accomplished significant progress in achieving implementation of adhesive bonded primary structure. Several items require further attention, and developmental programs are recommended for these items. The items requiring additional definition and improvement and their state-of-readiness are shown on table 7. Definition of each level of readiness is presented in table 8.

Recommended Action

In the following paragraphs, the recommended developmental areas and associated tasks are identified. These developmental programs would be conducted by an airframe contractor.

- **Material Development**
This program requires analysis and testing to determine the effects of variables associated with surface and core preparation, adhesive and primer characteristics, and exposure to in-service environment on durability and structural integrity of bonded primary structure. Material specification and minimum acceptable material characteristics would be derived from the results of this program.
- **Electrical Bonding**
This program requires analysis and developmental testing to evaluate and screen structural materials and develop design concepts. Typical hardware would be designed and tested for electrical continuity and structural integrity.
- **Repair and Production Changes**
This program requires analysis to establish repair requirements and design concepts. A follow-up structural testing program is required to verify the durability and structural integrity of repair designs and to provide repair design allowables.

The results of this repair program must be coordinated with the recommended manufacturing development program and damage tolerance program to establish minimum acceptable quality and to study the effect of rejection rates on feasibility of bonded aluminum structure.

TABLE 6.— BONDED ALUMINUM FUSELAGE AND WING STRUCTURE

Component	Weight increment per airplane			% DOC change	Net present value of change (300 airplanes)
	lb mass	kg	% of total structure		
Forward fuselage	-970	-440		-0.40	\$ 58 800 000 increase
Aft fuselage	-2450	-1110		-1.20	\$148 500 000 increase
Total fuselage	-3420	-1550	-2.9	-1.60	\$207 300 000 increase
Wing lower surface	-800	-363	-0.7	-0.48	\$ 55 050 000 increase

TABLE 7.—STATE OF READINESS, ADHESIVE-BONDED ALUMINUM STRUCTURE

Developmental area	Readiness rating					
	1	2	3	4	5	6
Design						
Joints and edges	X					
Tolerances	X					
Core machining	X					
Repair and changes				X		
Electrical bonding				X	X	
Damage tolerance						
Analysis						
Static		X				
Fatigue		X				
Fail-safe		X				
Concentrated loads		X				
Joints	X					
Stability		X				
Allowables						
Material	X					
Static	X					
Fatigue		X				
Environmental				X		
Combined loads		X				
Imperfections			X			
Materials						
Adhesives					X	
Primers				X		
Surface preparation				X		
Core		X				
Manufacturing						
Tooling	X					
Automation		X				
Inspection		X				
Final assembly				X		
Rejection rate				X		

TABLE 8.—STATE-OF-READINESS DEFINITION

Readiness Level

- ① Adequate understanding of the problem to circumvent or account for with essentially no risk to end item airworthiness or durability. Normal progressive efforts in the foreseeable future are expected to resolve the item.
- ② Item is well understood and identified by substantial testing, but is not resolved. This item could impact end item airworthiness. It is not considered pacing to end item progress, but is assumed to require resolution for a durable and airworthy structure.
- ③ An item known to affect durability, airworthiness or cost-effectiveness. Progress is not paced by this item, but developmental programs directed at this area are required.
- ④ An identified area of medium risk to end item airworthiness if unresolved. Mandatory resolution is not required prior to preliminary concept commitment, but developmental programs are required in this area and may pace other developmental areas.
- ⑤ An area known to represent an end item deficiency. Intermediate experimental structure research may proceed prior to resolution of this problem, but production commitment cannot be justified until developmental programs have indicated significant progress in this area.
- ⑥ An item having great impact on the overall structural concept. Inadequate resolution assumed to result in a high-risk end product. Basic and intensive research and development programs are required prior to, or along with, basic conceptual studies.

- **Damage Tolerance**
A developmental program is required to assess the damage tolerance of the bonded primary structure. Such a program would require an extensive analysis of fracture mechanics properties of the bonded structures and a comprehensive structural testing program.
- **Analysis**
Analyses and testing are required to investigate the following structural phenomena and to establish reliable analytical procedures.
 - Peel forces acting on the adhesive bond line in structures under compressive load.
 - Buckling behavior of curved sandwich panels under shear load or combined shear and compressive loads.
 - Effects of local stiffness and eccentric load paths in connection with fatigue evaluation of structural joints.
 - Fail-safe behavior of bonded primary structure.
 - Distribution of reacting loads through the adhesive bond line in the sandwich material due to high, local concentrated loads.
- **Inspection**
A program is required to establish nondestructive inspection methods for use during the manufacture of bonded primary structure. Inspection methods for in-service inspection purposes must also be developed. This program requires in-depth analysis of manufacturing methods, quality control procedures, and in-service inspection requirements. Inspection tools would be developed and verification testing would be conducted.
- **Manufacturing Methods**
Analysis is required to assess the impact of increase in size of assemblies. Automated methods for surface preparation, primer and adhesive application to the surface and core would be designed. Inspection methods developed in the program described above would be incorporated in the manufacturing cycle.

Impact of incorporation of large, highly stiff bonded subassemblies into final assembly will be analyzed. Effects of repair and production changes on manufacturing cycle would be analyzed.
- **Allowables**
Analyses and testing are required to develop standardized analytical methods to calculate strength, fatigue and fail-safe allowables. Additional tests and analyses are required to investigate the effect of imperfection in material and manufacturing process on the reduction of allowables. Further tests and analyses are required to establish the degradation of the allowables due to exposure of bonded structure to

environment during service experience. This program would influence the inspection methods and manufacturing process and will establish minimum acceptable quality.

- **Scale-up Hardware and Verification Testing**
Design, analysis and testing is required to verify the findings of the preceding recommended programs on a full-scale, large structure assembly. The scale-up test section is envisioned as a full-size fuselage section designed in bonded honeycomb structure, plus a full-size wing section designed with bonded skin and stiffeners. The test sections would include areas of complexity such as window and door cutouts, keel beam and frame structures. The test section would be subjected to realistic flight and ground load spectrum.

Cost and Schedule

The recommended developmental areas, funding level, and scheduling are outlined in figure 68.

Improved Corrosion Protection

Today's passenger transport aircraft are operating in widely varying corrosive environments that may result in premature airframe deterioration.

Potential Payoff

Corrosion protection can have a significant effect on reducing airline maintenance cost on aircraft structure. A review of corrosion protection systems on contractor commercial aircraft revealed two promising areas to study:

- Corrosion protection of upper surfaces of the wings
- Corrosion protection around nonaluminum fasteners in fuselage and empennage by wet installation of fasteners.

Three alternate methods of protecting wing cover panels were evaluated. (See table 9.) The three alternates were: improved paint, high-strength clad, and improved cladding plus improved heat treatment. For comparative assessment purposes, the baseline was a painted aluminum wing upper surface. The improved paint and high-strength cladding show the most potential and are recommended for development. To reduce the cost of wet installation of fasteners, the development of a precoated fastener is required.

State-of-Readiness

The high-strength aluminum alloys used for upper wing skins on contemporary aircraft are susceptible to intergranular exfoliation corrosion. This form of corrosion generally occurs at the countersink area of fastener holes where moisture entrapment and end grain exposure are both present. The contractor has been successful in inhibiting this form of corrosion on

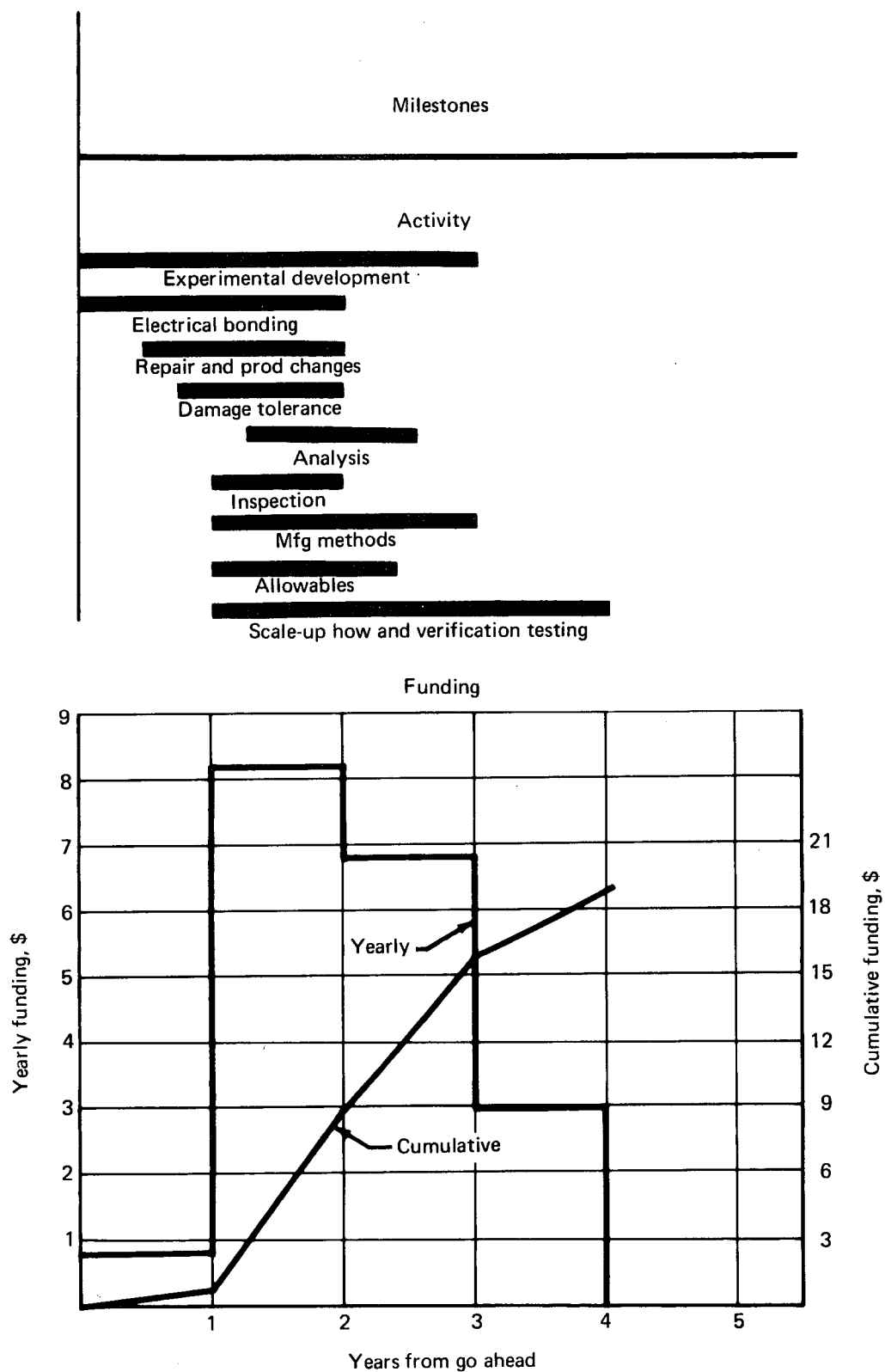


FIGURE 68.—DEVELOPMENT OF BONDED ALUMINUM STRUCTURE FUNDING SCHEDULE

TABLE 9.—EXFOLIATION CORROSION PROTECTION

	Weight increment		Drag increment (equivalent weight)		Change to DOC, %	Net present value of change (300 airplanes)
	lb/apl	kg/apl	lb	kg		
Alternate 1 Improved paint	+10	+4.5	-500	-227	-0.25	\$20 250 000 increase
Alternate 2 High-strength clad	-20	-9.0	-500	-227	-0.25	\$28 260 000 increase
Alternate 3 High-strength clad plus improved heat treat	+680	+308	-500	-227	+0.10	\$ 1,100,000 increase
Coated fasteners	0	0	0	0	—	\$1 860 increase

upper wing skins by painting with an aluminum filled polysulphide modified vinyl. However, it does not dry to a smooth surface, and requires fairly frequent repainting to maintain a good appearance. Alternate solutions to the exfoliation corrosion problem and their state of readiness are discussed below.

A new flexible polyurethane paint, smoother than the vinyl, has recently become available. This paint system is fully developed and has been applied to the upper surface of two 747 airplanes. To date, this paint system has been in service for several months, and no problems have developed. If this system continues to show good corrosion protection for two more years, it will likely be substituted for the vinyl system.

The problem with paint roughness can be eliminated by using unpainted upper wing skins. Either 7008 or 7011 alclad 7075-T651 can be used. These new clad alloys are very similar in composition, and both have mechanical properties similar to those of the base material (7075-T651). Both have higher allowables than the current lower strength 7072 clad 7075-T651. In addition, whereas the regular alclad 7075-T651 could not be peen-formed because of the layer of lower strength 7072 clad material, the high strength clad alloys can be peen-formed. However, new alloys must be peen-formed using low velocity, large diameter balls. This procedure eliminates the need for sanding which is required after peening with high velocity, small diameter balls. Elimination of sanding is necessary since this could remove the alclad metal.

Typical mechanical, fatigue, and corrosion properties are not available for the new high strength clad materials. A test program is required before design data can be determined and a material specification prepared.

Recommended Action

In addition to the flexible polyurethane enamel currently being evaluated on two 747 airplanes, eight new paints have been submitted for evaluation to the contractor by different vendors attempting to meet the requirements for a more flexible air-drying enamel. A funded program is recommended for further development of the most desirable candidate. This program would involve a one-year development study by a paint manufacturer under subcontract to the airframe manufacturer. At the conclusion of this program, the improved paint would be evaluated, including flight testing for two years, and a specification prepared covering the new material.

Before peen-forming a high strength clad 7075-T7651 can be implemented, a three-phase investigation is recommended.

Phase I would determine the feasibility of large diameter ball shot-peening as a satisfactory method for contouring the wing skin material. This study would require that test work be conducted on a gravity ball machine. Particular emphasis should be placed on determining surface finish acceptability and equipment requirements.

Phase II should consist of selecting and/or specifying the proper equipment and establishing process parameters. An effort should be made to modify existing shot-peening equipment to minimize capital expenditures. Process documentation would also be accomplished during this phase.

A full-scale hardware demonstration will be conducted during Phase III.

Before the precoated fastener system can be implemented, identification of vendors who can apply the sealant film to the designated area of the fastener at a controlled thickness would be required. A development program between the contractor and a fastener vendor is recommended to accomplish this goal. A specification covering the coatings would be established.

Cost and Schedule

The recommended development funding and calendar schedule for the solutions proposed in this trade study are shown in figure 69.

Titanium Structures

Both conventional and honeycomb sandwich construction were considered using 6Al4V titanium alloy. This material was substituted for aluminum in the wing box, fuselage, keel beam, and wing center section and evaluated for structural weight and operational cost differences.

Potential Payoff

The areas of major potential weight savings are in the wing and fuselage. Payoff was evaluated using 6Al-4V titanium for conventional and both brazed and adhesive bonded honeycomb sandwich structure. Weight savings ranging from 0.1 to 1.8% of total airplane structure were realized in studies on the wing box, wing center section, fuselage keel beam and over-wing area. The weight and cost results, shown in table 10 indicate cost effectiveness only on the keel beam.

State-of-Readiness

Among the many previous development programs, the B-70, SR-71 and SST stand out as the major efforts. Current major programs include the SST Phase I follow-on, the B-1, the F14, and the F-15. An SST Phase II follow-on is proposed for the near future, to be funded by the Department of Transportation. These programs bring titanium structural development, honeycomb and conventional, to a state of near completion for subsonic aircraft use.

Recommended Action

Due to the high costs associated with the weight reductions in panel construction, no NASA development efforts are recommended at this time. However, for airplanes with cruise speeds above Mach 1, the use of titanium becomes more and more cost-effective as speed and

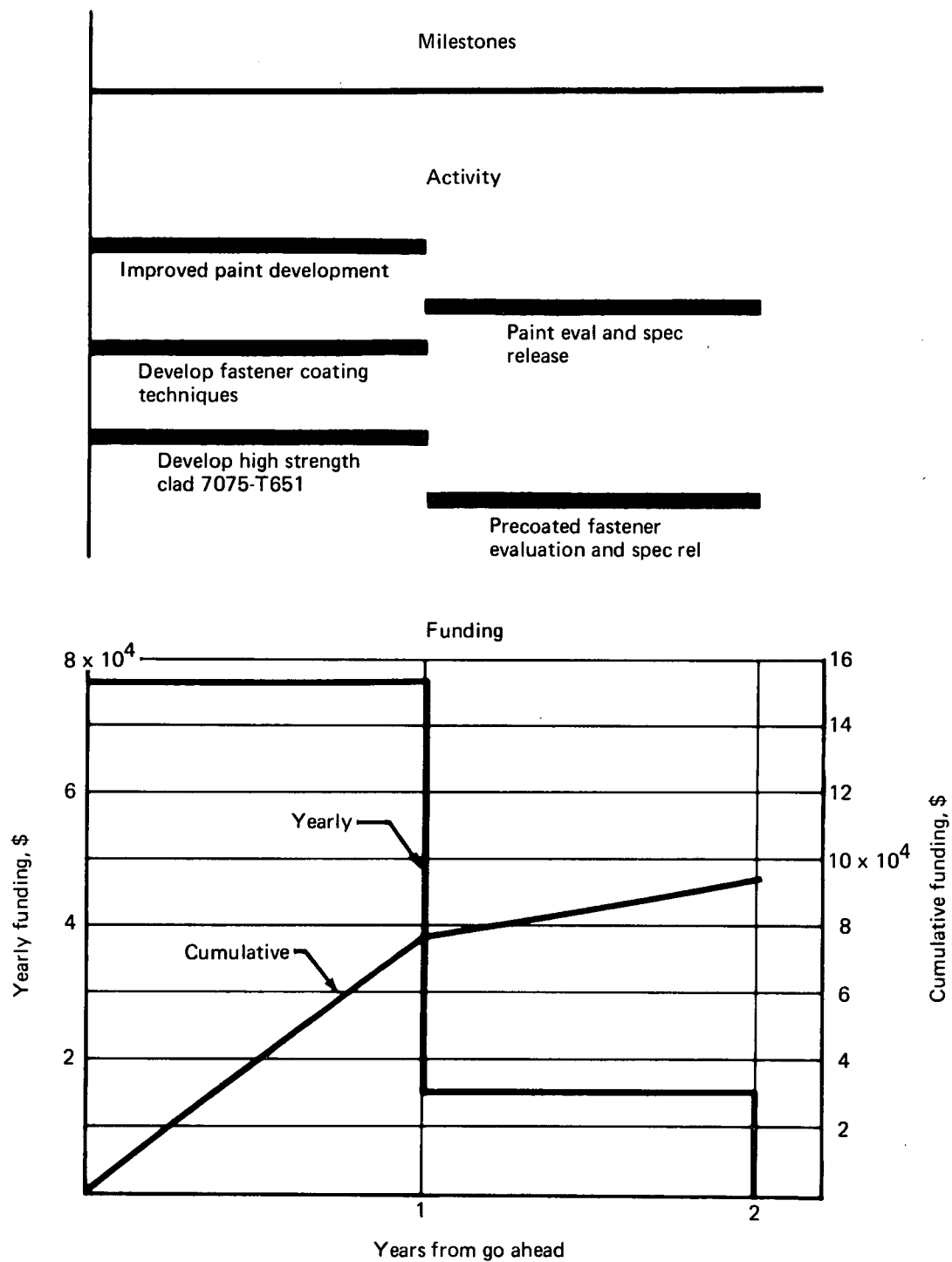


FIGURE 69.—DEVELOPMENT OF MORE COST EFFECTIVE CORROSION PROTECTION SYSTEMS FUNDING SCHEDULE

TABLE 10.— TITANIUM STRUCTURE

	Type of construction	Weight increment per airplane		% of total structure	Net present value of change (300 airplanes)
		lb mass	kg		
Wing box	Brazed honeycomb	-2120	-936	-1.8	\$302 700 000 decrease
Wing box	Bonded honeycomb	-2110	-958	-1.8	216 000 000 decrease
Wing center section	Conventional	- 340	-155	-0.3	3 600 000 decrease
Fuselage overwing	Brazed honeycomb	- 660	-300	-0.6	26 700 000 decrease
Fuselage overwing	Bonded honeycomb	- 660	-300	-0.6	12 000 000 decrease
Fuselage overwing	Conventional	- 590	-268	-0.5	2 700 000 decrease
Keel beam	Conventional	- 80	- 36	-0.1	1 800 000 increase

structural temperatures increase. At speeds approaching Mach 3, as for the SST, the substitution of titanium (or other high temperature material) for aluminum becomes mandatory. For these reasons, the status of titanium development and the potential benefits of its use on future aircraft must be continually monitored.

Improved Steel Structures

Both conventional and honeycomb sandwich construction was considered using AFC 77 stainless steel alloy. This material was substituted for aluminum in the wing and fuselage and for conventional aircraft steel in the landing gear and trailing edge flap tracks. Weight and cost differences were evaluated between the components of conventional material and those of AFC 77.

Potential Payoff

The most promising candidate alloy is AFC 77 stainless steel. Since this material can be made available in sheet and forgings, payoff was evaluated for adhesive bonded honeycomb sandwich as well as conventional structure. Studies on the wing box, over-wing fuselage, main landing gear and trailing edge flap tracks resulted in weight savings ranging from 0.1 to 2.4% of total airplane structure. The weight and cost results, shown in table 11, indicate cost effectiveness only on forged structure.

State-of-Readiness

The Air Force has funded two previous AFC 77 development programs, one for material development and another for machining. Currently, a program is being funded by the Air Force to determine the mechanical properties of large forgings of this material. Two Air Force programs are expected in the near future in connection with fabrication of continuous rolled sheet and seamless tubing. These efforts make up only a small percentage of the total development required for commitment of honeycomb sandwich and forged structures on a commercial aircraft.

Recommended Action

Due to the high costs associated with the larger weight savings and because of the apparent continued funding by the Air Force, no further development efforts are recommended at this time. However, the development status of this material must be continually monitored to assess its potential on future aircraft. Higher airplane speeds and temperatures may dictate materials other than aluminum, or as development continues the fabrication costs may be revised downward. Funding of development aimed toward commercial aircraft may be desirable at that time.

Integrated Active Controls

Control systems can be used effectively to reduce structural material requirements and thus airplane operating empty weight. The magnitude of the payoff is sensitive to the configuration. This means that the maximum benefit of a load alleviation control system will be

TABLE 11.— IMPROVED STEEL STRUCTURE

	Type of construction	Weight increment per airplane		% of total structure	Net present value of change (300 airplanes)
		lb mass	kg		
Wing box	Bonded honeycomb	-2860	-1298	-2.4	\$281 400 000 decrease
Trailing edge flap tracks	Forging	- 160	- 73	-0.1	4 200 000 increase
Fuselage overwing	Bonded honeycomb	- 650	- 295	-0.5	20 400 000 decrease
Main landing gear	Forging	- 160	- 73	-0.1	5 500 000 increase

obtained on an airplane configured for the system from the outset. An Integrated Active Control System trade study conducted on the -611 airplane is described in Volume I of this report.

Potential Payoff

The payoff for a system including maneuver load alleviation (MLA) and gust load alleviation (GLA) was determined in terms of operating empty weight saved and cost per pound of weight saved. Maneuver load alleviation was achieved with outboard spoilers and GLA was achieved with the aft segment of the mid-semispan flap. The payoff for reduced airplane stability and a recommended program for realizing this payoff is discussed in the Control of Flight section. Flutter mode control (FMC) was not weight-effective for the -611 airplane. However, the feasibility of an FMC system was studied because it could be very weight-effective on configurations where considerable weight is required for flutter stability. The structural load alleviation payoff shown in table 12 is based on the savings in net wing weight. Additional weight may be saved in the horizontal tail and body structure. Weight saving cost for the integrated active control system is \$72/lb (\$159/kg).

State-of-Readiness

The use of control systems in airplane stability augmentation, maneuver load alleviation, gust load alleviation, ride improvement and flutter mode control have been theoretically analyzed. Some of the concepts have been demonstrated by flight test programs. Figure 70 summarizes related programs which have been completed or which are committed. In addition, the fly-by-wire systems currently under development, are a necessary requirement for advancing active controls technology.

The ECP 1195 program demonstrated that installation of state-of-the-art pitch and yaw stability augmentation systems on the B-52 airplane, significantly reduced fatigue damage rates and peak loads in the aft body, without degrading the flutter margin or ride quality. The LAMS program demonstrated that control systems installed in the B-52 airplane to alleviate wing gust loads and control structural modes provided significant reduction in fatigue damage rates. The analysis methods developed for the LAMS study were verified and can be applied to other airplane studies. The SST SAS development program evaluated the design of a flight critical stability augmentation system and the feasibility of detecting some critical failure combinations. A method was developed in the laboratory to detect these failures during preflight and inflight monitoring. A technique for flutter suppression using active controls based on the concept of aerodynamic energy was developed by the NASA (reference 5). Analytical techniques and wind tunnel model test methods are being developed for application of this concept.

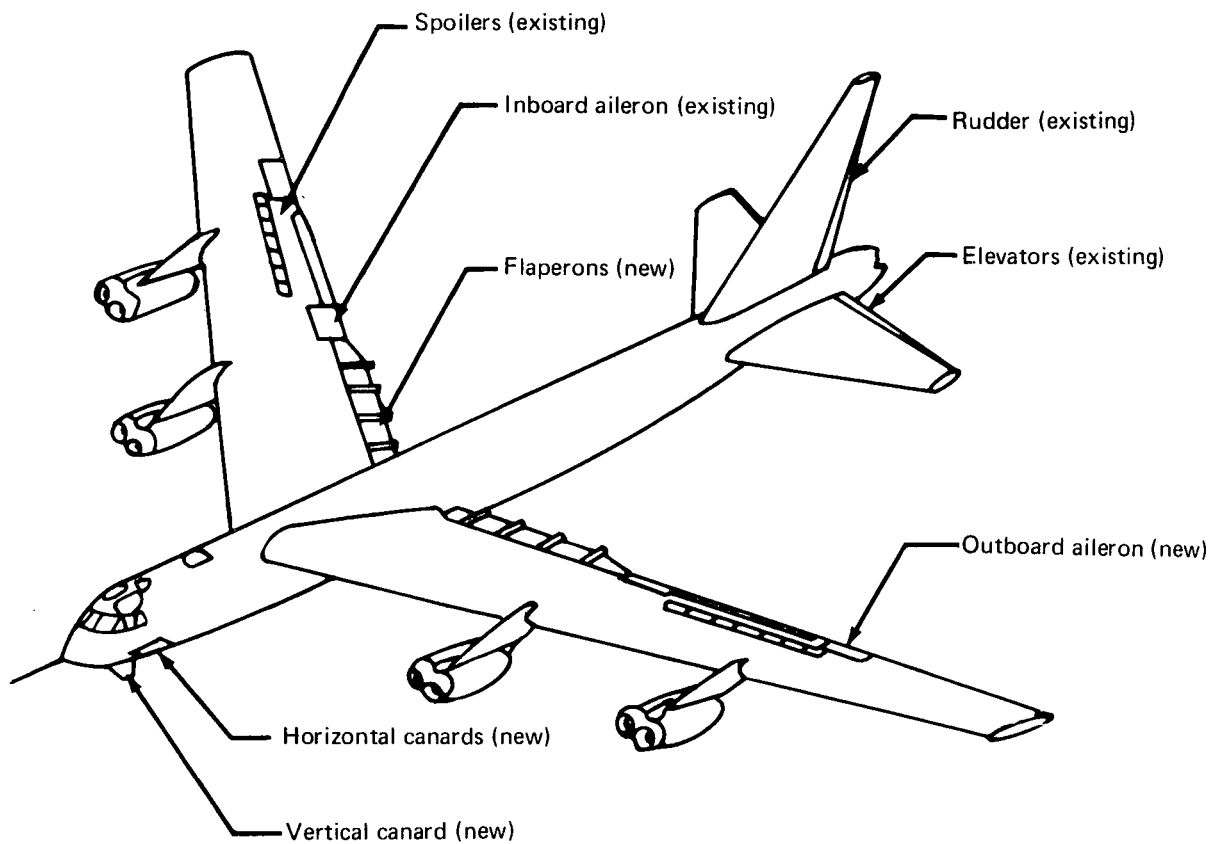
The control configured vehicle (CCV) program will provide flight validation of the benefits obtainable from advanced flight controls concepts using the LAMS B-52 as the test vehicle. Concepts to be demonstrated included augmented stability (AS) of a relaxed static stability configuration, ride control (RC), maneuver load alleviation, flutter mode control, and modified LAMS gust load alleviation. The concepts will be evaluated independently and collectively to determine overall system compatibility. The control surfaces used for each concept are illustrated on figure 71. Conventional trailing edge surfaces are used for MLA. The results

TABLE 12.— INTEGRATED ACTIVE CONTROL SYSTEM WEIGHT SUMMARY AND PAYOFF

<u>Wing box material savings</u>	<u>Lbs.</u>	<u>Kg</u>
Upper surface	1570	(712)
Lower surface	2140	(971)
Shear and rib material	<u>530</u>	<u>(150)</u>
Total structural weight saved	4040	(1833)
 <u>Material added</u>		
Structural modifications outboard wing box:		
● Strength requirements	1100	(499)
● Stiffness requirements	230	(104)
Spoiler structure	<u>410</u>	<u>(186)</u>
	1740	(789)
 <u>Systems added</u>		
Maneuver load alleviation	175	(79)
Gust load alleviation	420	(190)
Flutter mode control not weight-effective, and therefore was not integrated into system.	<u>0</u>	<u>0</u>
	595	(269)
<hr/>		
Net system payoff	1705	(773)
<hr/>		

Concept	Pay-off trade data		System mechanized		Test verification	
	Military	Commercial	Military	Commercial	Ground	Flight
Reduced Stability	B-52 818 KCX	F-4 C-5 ATT SST	B-52	SST	B-52	0
Maneuver Load Alleviation	B-52 818 KCX	F-4 C-5 ATT	B-52	0	B-52	0
Gust Load alleviation	B-52	0	B-52	0	B-52	0
Fatigue	B-52	ATT	B-52	0	B-52	0
Flutter Mode Control	B-52	SST	B-52	0	B-52	0
Ride Quality Control	B-52 B-70 B-1	C-5 SST LWL STOL	B-52 B-70 B-1	0	B-52 B-70	0
Engine Out Control	4-E B-52	SST	0	0	0	0
Landing load alleviation	0	0	0	0	0	0

FIGURE 70.—STATE-OF-READINESS



Surface		Surface required per concept				
		AS	RC	MLA	GLA	FMC
Existing	Inboard aileron				x	
	LAMS spoilers				x	
	Elevator	x	x	x	x	
	Rudder	x	x		x	
New	Horizontal canards		x			
	Vertical canard		x			
	Outboard aileron			x		
	Flaperons (3 seg)		x	x		x

FIGURE 71.— CCV FLIGHT CONTROL SURFACES

of the Integrated Active Control trade study showed that the most optimum lift and moment distributions require unique control surfaces for MLA. Theoretical tools are available that would allow the design of such surfaces. Since this has not been accomplished to date, configuration optimization should follow the development and testing of such controls.

The SST Iron Bird follow-on program extends the evaluation of SAS development to include complete longitudinal control system hardware with a quadruply redundant fail-operational-squared system. This same type of testing will also be required for the flight critical MLA and FMC systems.

Recommended Action

Although the basic technology for design of a structural alleviation control system has been demonstrated, additional research programs are required before these systems can be committed to commercial airplane programs. This research work should be performed in a series of related tasks.

Control Surface Development.—The successful application of load alleviation systems depends to a large extent on being able to predict the control surface effectiveness, throughout the operating envelope, with a high degree of confidence. Effects such as Reynolds Number, compressibility, nonlinearities and flexibility must be well understood. The NASA should initiate a study to be conducted by an airplane manufacturer familiar with the design of large jet transports. The study should include the following items:

- define the desired wing load distribution
- Theoretically determine possible wing control surfaces
- build and wind tunnel test the theoretically determined control surfaces
- select the surfaces and aerodynamic characteristics to be used in configuration studies.

Configuration Development.—The maximum benefit of load alleviation concepts will be realized by developing an airplane configuration based on the concepts, rather than adapting load alleviation controls to a configuration based on a conventional design approach as shown in figure 72. A follow-on contract should be issued to the control surfaces development contractor to develop a configuration as follows:

- define the airplane mission in terms of Mach number, payload, range, flight envelope, and propulsion system characteristics.
- optimize the configuration for best performance, recognizing that the wing/empenage geometry, balance philosophy, and system complexity all impact the performance as shown in figure 73.

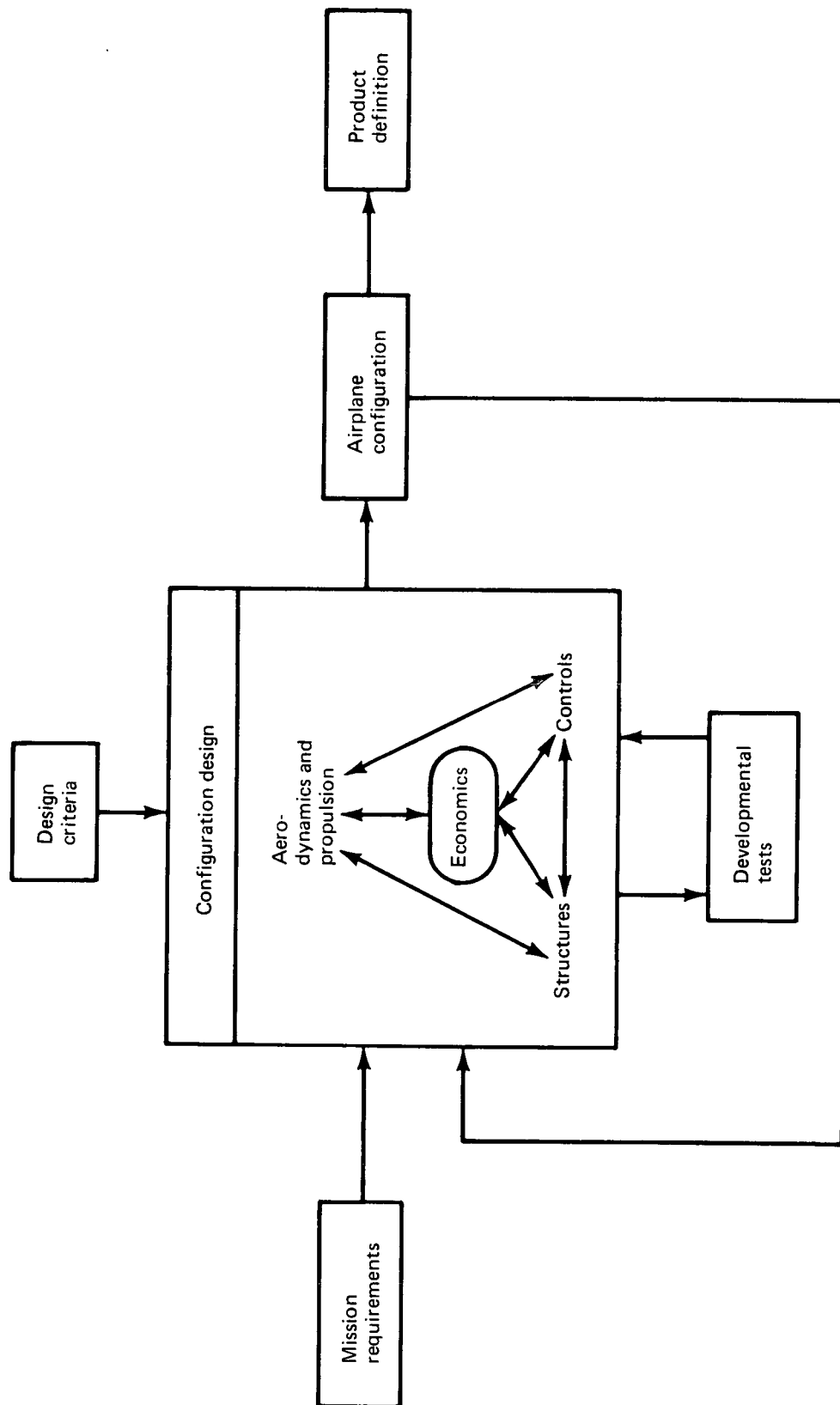


FIGURE 72.—INTEGRATED DESIGN APPROACH

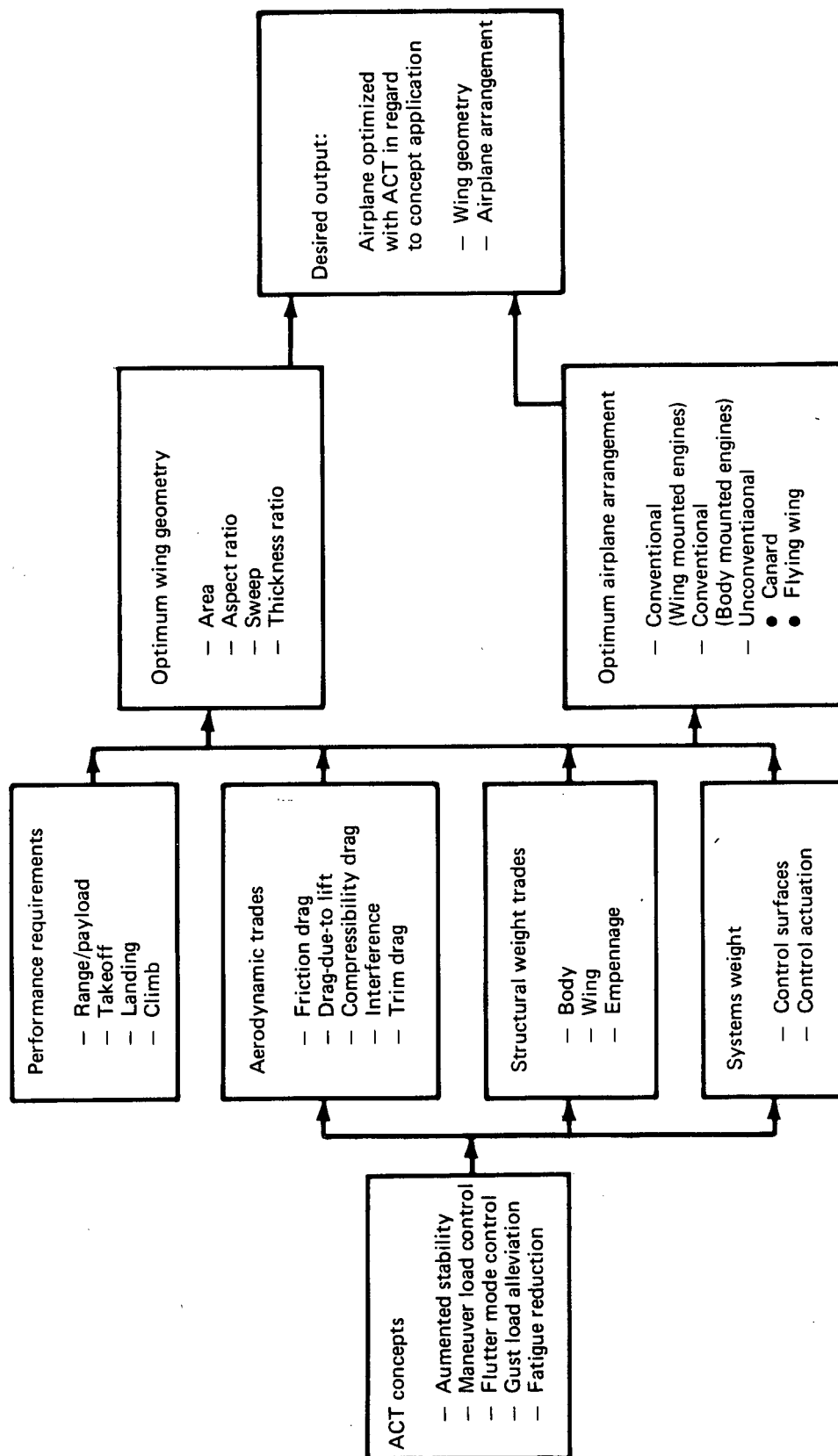


FIGURE 73.—CONFIGURATION DEVELOPMENT

Flutter Suppression.—Successful development of a flutter mode control system depends to a large extent on understanding the effects of unsteady aerodynamics for rapid control surface motions. The NASA should initiate research contracts to:

- develop analytical methods to predict the oscillatory aerodynamics of the control surfaces.
- build and wind tunnel test two dimensional dynamic control surface models.
- develop an FMC system for the configuration designed for maximum load alleviation benefit.
- build and test a large three dimensional dynamic model of the selected configuration with FMC.

Control System Development.—Flight critical systems require hardware developed to meet maximum standards of safety, reliability and maintainability. In addition, failure monitoring techniques are required. The NASA should initiate a contract with a contractor who has experience and facilities for control system hardware evaluation. Tasks to be performed are:

- build control system hardware
- laboratory test the hardware
- evaluate the integrated control system on an iron bird
- develop the design validation and certification program definition, cost and schedule

Design Validation and Certification.—Validation of the system, or parts of the system under actual flight conditions will provide the degree of confidence required prior to incorporating these concepts into commercially certifiable transport airplanes. The flight test program could be accomplished by using existing airplanes.

Cost and Schedule

The estimated cost and schedule is shown in figure 74. The tasks leading to validation and certification would require an expenditure of 2.9 million dollars over a period of 24 months. Cost and schedule for the design validation and certification task are preliminary. More detailed data should be provided as part of the configuration development task.

Structural Design Methodology

This section identifies research tasks directed toward improving the design and analysis methods that would be used in developing an Advanced Technology Transport. Developments are described which are needed to support design for the transonic flight regime and advance the general state-of-the-art in design analysis.

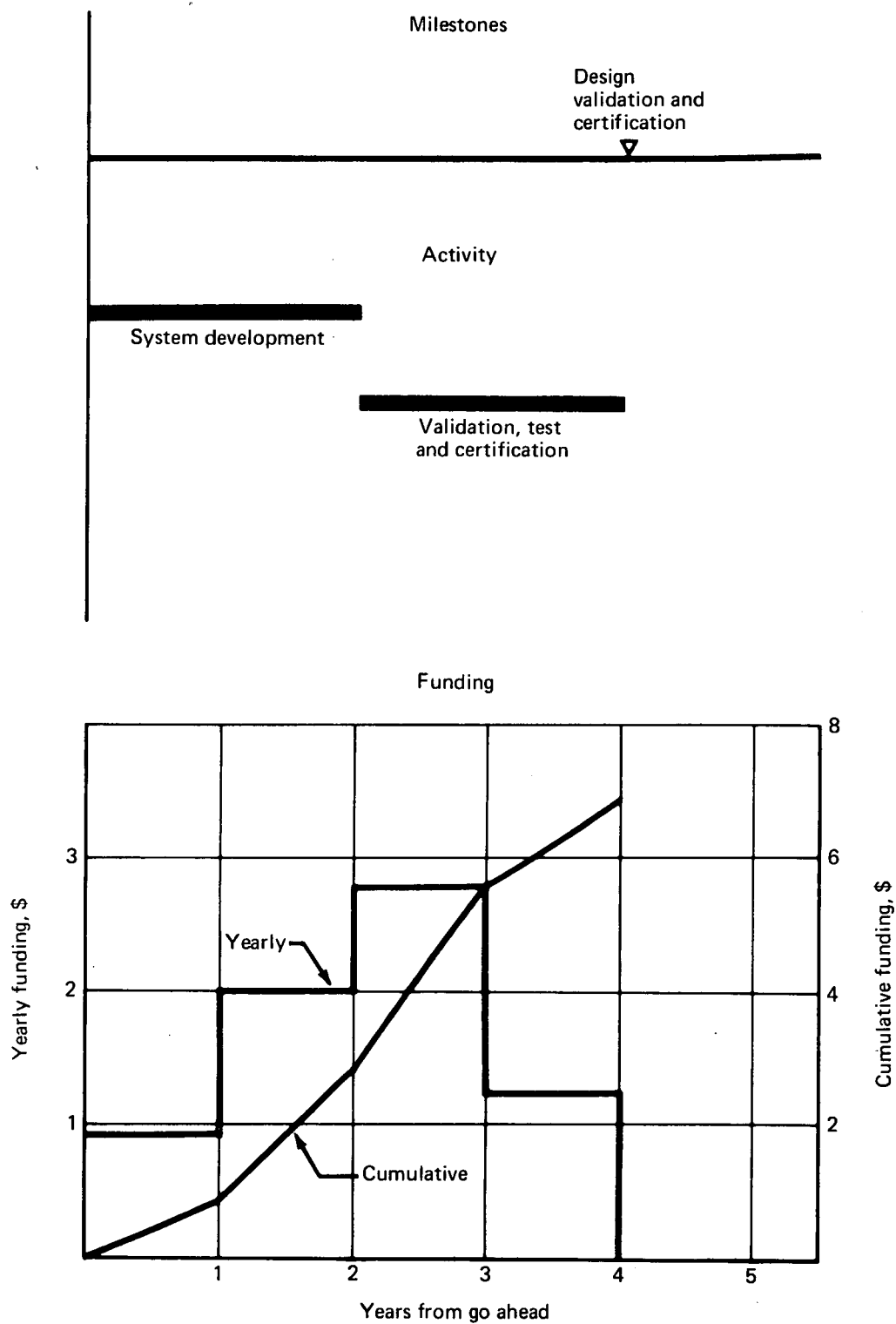


FIGURE 74.—ACTIVE CONTROL SYSTEM DEVELOPMENT FUNDING SCHEDULE

Potential Payoff

The potential payoff of improvements to methodology fall into three general categories.

- Establish a better basis for making design decisions by improving analysis flow time.
- Improve structural efficiency without increasing risk or reducing safety by providing a better base for determining material requirements.
- Establish a sound basis for assuring adequate service life with minimum structural maintenance.

A definite need exists for improved analysis techniques in the areas of:

- Loading environment
- Gust loads analysis
- Transonic unsteady aerodynamics
- Nacelle and cowl aerodynamics
- Integrated structure design

Loading Environment

State-of-Readiness.—The structural life of an airplane is dependent on the loading environment in flight and on the ground. In order to predict the structural fatigue characteristics, loads existing during normal airplane operation are required. The NASA VGH program (velocity, acceleration, altitude) has provided a great deal of information on the vertical accelerations encountered during normal operations. However, these data are insufficient to completely define the environment.

Recommended Action.—The NASA should initiate a follow-on program to the VGH program. In addition to vertical acceleration, airspeed, and altitude, additional measurements should include major component loads, or airplane response parameters from which loads can be obtained, and an indication if the yaw damper or autopilot is active. The data analysis program should provide accurate information on structural loads during flight in turbulence, pilot maneuvers, ground handling, and flight crew training. Compatibility in the analysis of data from each of the airplanes monitored, would depend on having a consistent set of airplane parameters.

Gust Loads Analysis

State-of-Readiness.—The present methods of gust loads analysis have proven to be generally adequate for strength design of aircraft. Over the past several years government contracts have been directed toward establishing criteria and analysis methods. Questions still remain on the atmospheric environment and detailed application of the criteria.

Recommended Action.—The NASA should issue contracts to industry as well as perform in-house studies to:

- Examine in detail the application of discrete and power spectral density gust criteria.
- Determine whether the criteria are consistent with the available data on atmospheric environment.
- Investigate the influence of combined random loads on structural design.
- Develop a gust analysis computer program which incorporates both structural dynamic modes and the residual stiffness not accounted for by the dynamic modes.

Transonic Unsteady Aerodynamics

State-of-Readiness.—The need to refine technologies of flutter prediction in the transonic range is a major problem in design of a Mach 0.98 airplane. The method used in this contract was based on matching the steady state lift distributions for each Mach number with measured distributions. These distributions were combined with the unsteady subsonic functions. The uncertainty of this method is magnified, relative to a conventional airplane, due to the unknown oscillatory aerodynamic characteristics of the supercritical wing.

Recommended Action.—The proposed research program should consist of theoretical research on an oscillating airfoil near Mach 1.0 supplemented by flutter model testing of both conventional and supercritical wings. This program should have both NASA and industry participation. Steady-state and oscillatory pressure measurements are required on a supercritical wing. These test data could be used to establish theoretical first order corrections to computer programs.

Nacelle Cowl Aerodynamics

State-of-Readiness.—Analytical and experimental work performed on the 747 airplane have demonstrated that large cowl, high bypass ratio nacelles have an important effect on wing flutter. Nacelle unsteady airloads are currently approximated using a horizontal and a vertical flat plate to represent the cowl. The sizes and lift curve slopes of the panels are based in model test results. This yields approximate results.

Recommended Action.—The NASA should initiate a program to be conducted by a manufacturer with experience using high bypass ratio engines. The program should include:

- Development of theoretical nacelle cowl unsteady aerodynamics.
- Measurements to determine the unsteady nacelle derivatives.
- Measurements to determine the effect on the unsteady aerodynamics of nacelle-wing interference.

Integrated Structural Design

State-of-Readiness.—The quality of an airframe structural design is based upon the quality of the technology used, and the timeliness with which that technology can be applied relative to design schedules. A quality design is most effectively accomplished when the several contributing disciplines act as a coordinated team and are able to cycle the design a sufficient number of times to fully assess critical responses. Several integrated systems (CPDS, ATLAS, MIDAS, IDEAS, MAGIC ADP and NASTRAN) have been developed by industry and government. However, each of these systems is limited in technical scope or in system design. Hence, there is not in existence today a system of computer code capable of including the total requirements for overall airframe structural design. The NASA is currently negotiating contracts with aircraft manufacturers for a feasibility study of an Integrated Program for Aerospace Vehicle Design (IPAD) intended to meet the requirements described above. IPAD will provide an adequate executive and data management system. Existing analysis capability will be integrated into the IPAD system. However, adequate strength and stiffness design will need to be developed. Further, to make the large volumes of data useful to the design engineer, a data processor will need to be developed.

Recommended Action.—The Following developments are proposed to enhance the scope NASA should fund industry to develop technical models to perform the following design and data processing functions:

- Develop an automated flutter solution module to determine the flutter speed, frequency and mode.
- Develop an automated strength design capability of adequate capacity for aircraft structure, based upon a fully stressed concept. This module should include provision for deflection constraints, minimum gages, local plate buckling and diagonal tension fields.
- Develop an automated stiffness design capability based upon parametric studies of structural stiffness using substructuring and modal synthesis.
- Develop a data processing module for selective processing, manipulating, plotting and documenting of pertinent items from the design and analysis data.

Cost and Schedule

Figure 75 reflects a four year program funded to a total of \$5.5 million.

POWER SYSTEMS

This section contains recommendations for advanced technology development of the aircraft power systems including the main propulsion system and all auxiliary systems. These recommendations are based on environmental and economic goals that are believed to be attainable as a result of a well-directed, sustained research and development program. The goals and program elements of these recommendations are discussed under the three main

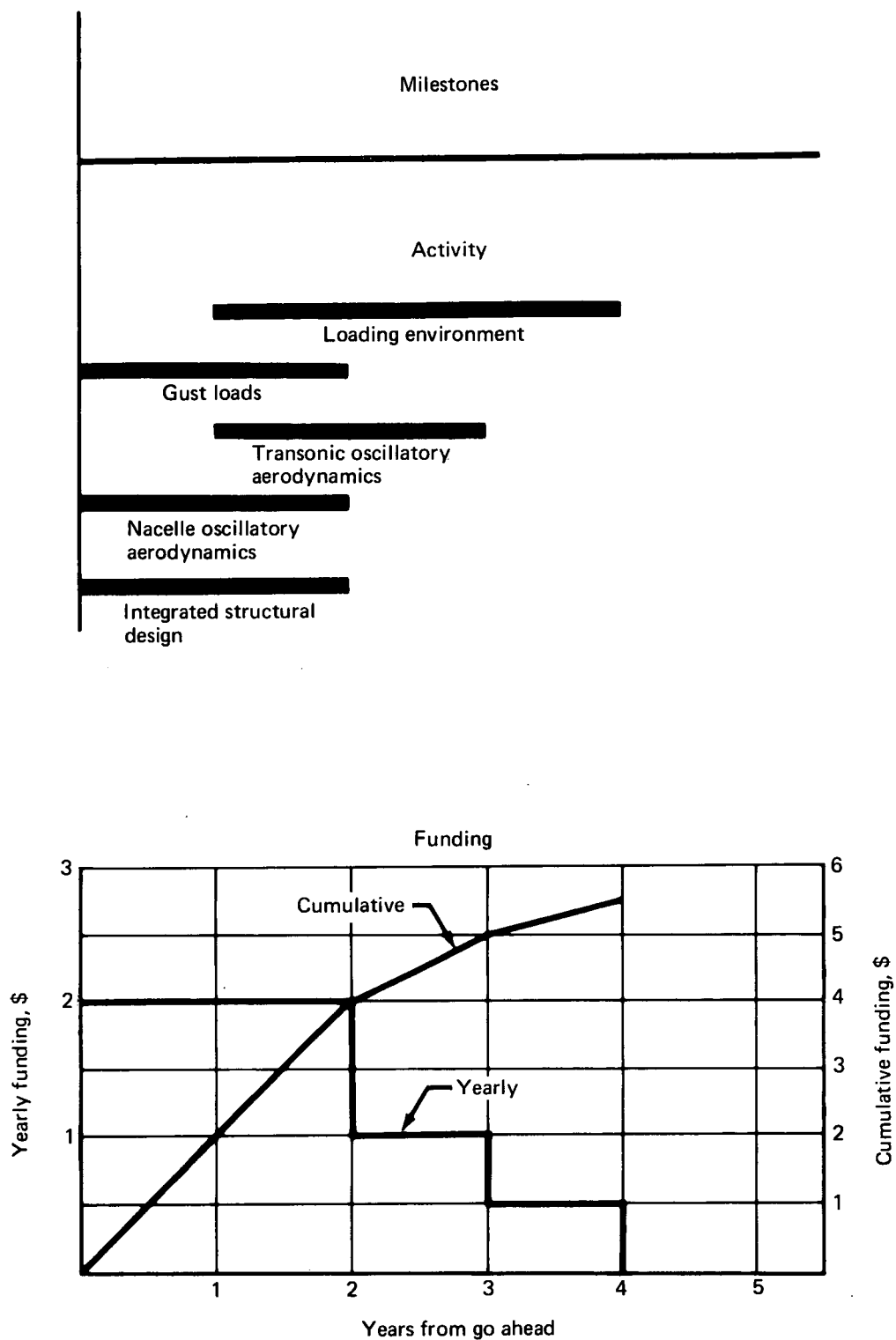


FIGURE 75.—STRUCTURAL DESIGN METHODOLOGY DEVELOPMENT FUNDING SCHEDULE

headings shown at the top in figure 76. These are Propulsion System Flight Demonstration; Community, Ramp and Interior Noise; and Advanced Auxiliary Systems. Under the Propulsion System Flight Demonstration heading, discussion is provided for three subordinate subjects.

The overall objective of the recommended effort is to demonstrate the achievability of the identified goals together with development of specific design technology which will decrease the risk of introducing a quieter, more pollutant-free, advanced transport airplane. The recommended collective power systems program as shown in figure 76 is estimated to provide noise reductions, at little or no performance penalty, of 10 to 20 EPNdB relative to today's technology. In addition, improvements of about 5% in airplane DOC, at constant aircraft noise, are believed attainable. The data in figure 77 illustrates that the advanced technology benefits may be realized in terms of: further DOC improvement at constant noise; or, noise improvement at constant operating cost; or, some combination of the two. This data was developed in conjunction with the Phase II configuration studies under more limited assumptions of technology advance.

An estimated total cost of approximately \$300 million will be required to support the recommended program. Cumulative funding plotted in terms of years from go-ahead is shown in figure 78. The figure also shows key program milestones in terms of a potential advanced aircraft program schedule. This reference airplane program has been used to provide focus for the recommended research and development efforts and key milestones from it will be related to the individual program schedules discussed subsequently.

To develop the material presented in the Power Systems section, quantitative, realistic goals in terms of weight, drag, sfc, noise, and emissions were identified in each of the detailed Power Systems elements depicted in figure 76. The research and development programs summarized in figure 78 were then developed to encompass fundamental research, concept development, configuration development, and large-scale hardware demonstration. This included development of estimated schedules and costs for each individual program. Two important points should be made concerning the program recommendations:

- Although the program goals and schedules were developed in terms of the detailed Power Systems elements, this level of detail could not reasonably be presented here. Rather, the summary benefits and costs are grouped under the six major work areas shown in figure 76 and the reader is referred to appendix A and to table 4 for more details. The early phases of three of the work areas are subelements of the Propulsion System Flight Demonstration program. The flight demonstration program would address the most critical propulsion design considerations at an early period, and provide the basis for a production engine go-ahead. It would not, however, satisfy the total large-scale testing needs for the engine/nacelle technology development required for commitment to a production program. Thus auxiliary tasks which proceed in parallel to the flight demonstration are planned. These would ensure that the commitment to a production propulsion system includes consideration of interim technology advances and incorporates experience from the demonstrator program.

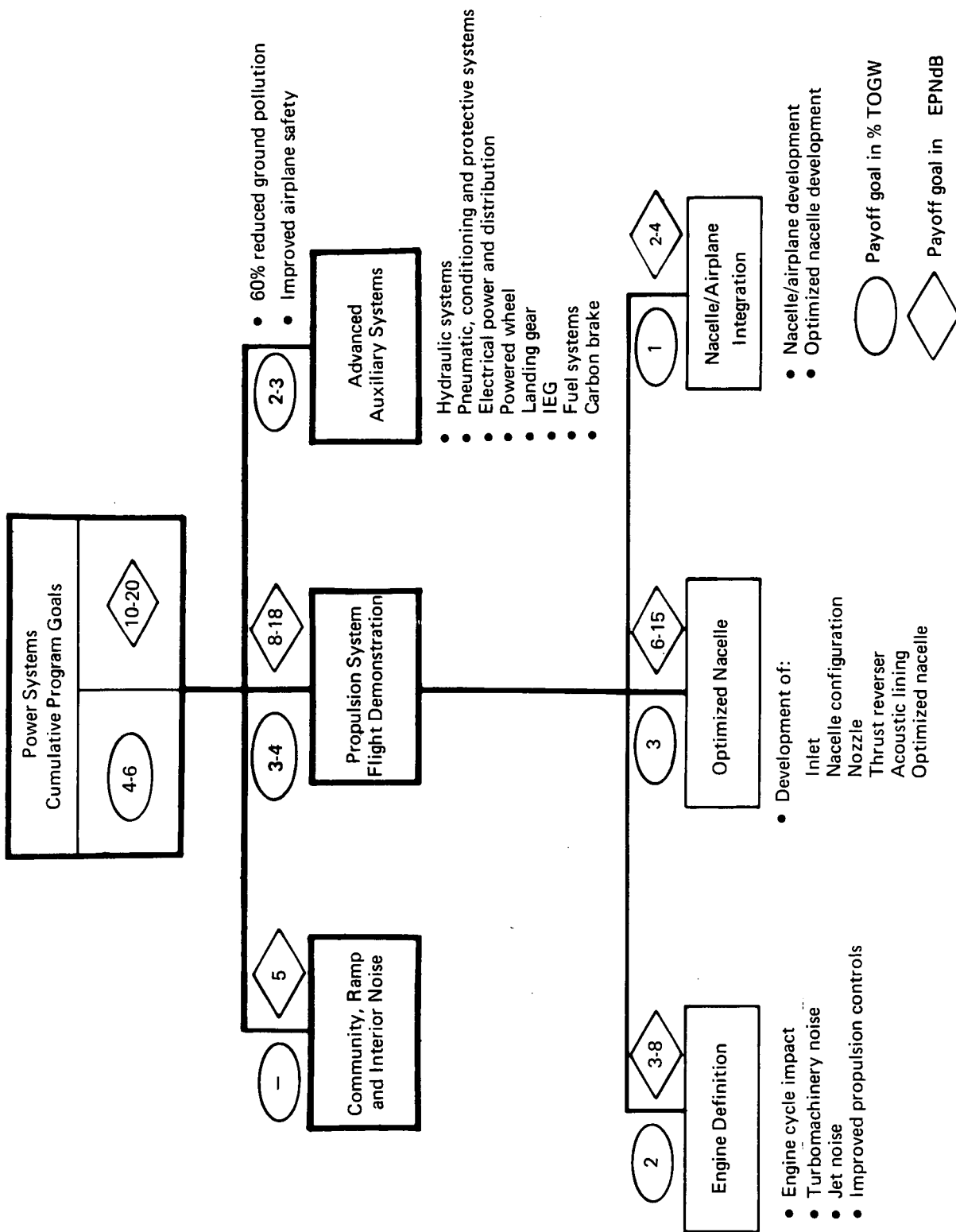


FIGURE 76.—POWER SYSTEMS ADVANCED TECHNOLOGY PROGRAMS

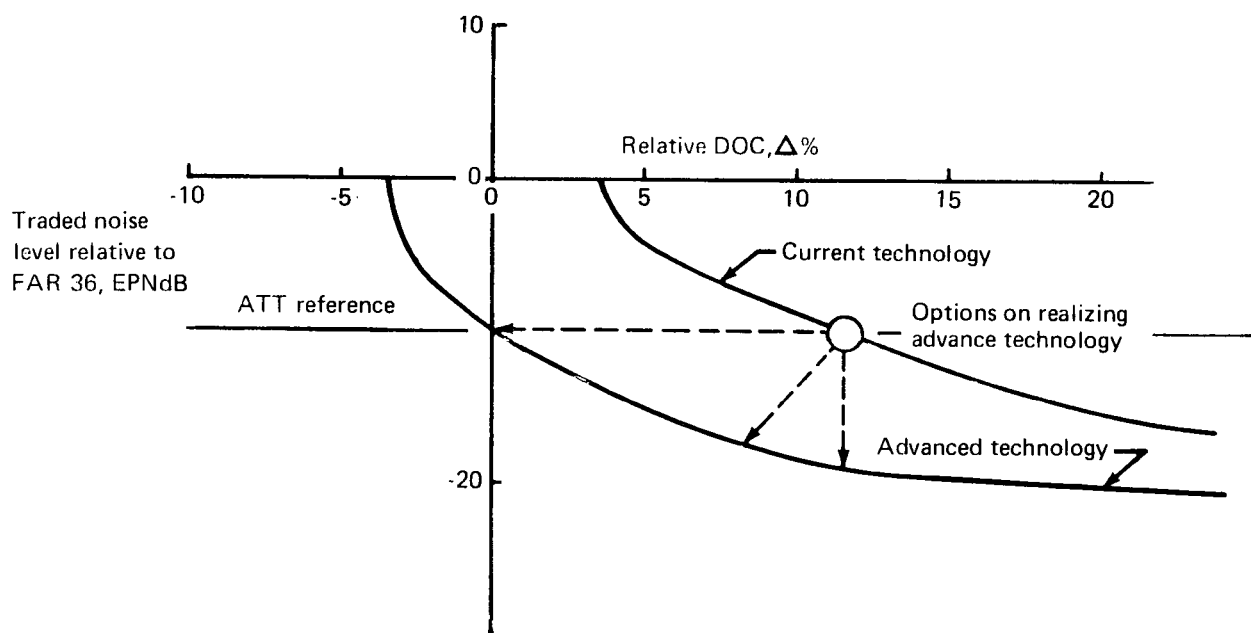


FIGURE 77.— EFFECT OF ADVANCED TECHNOLOGY
ON NOISE VERSUS DOC

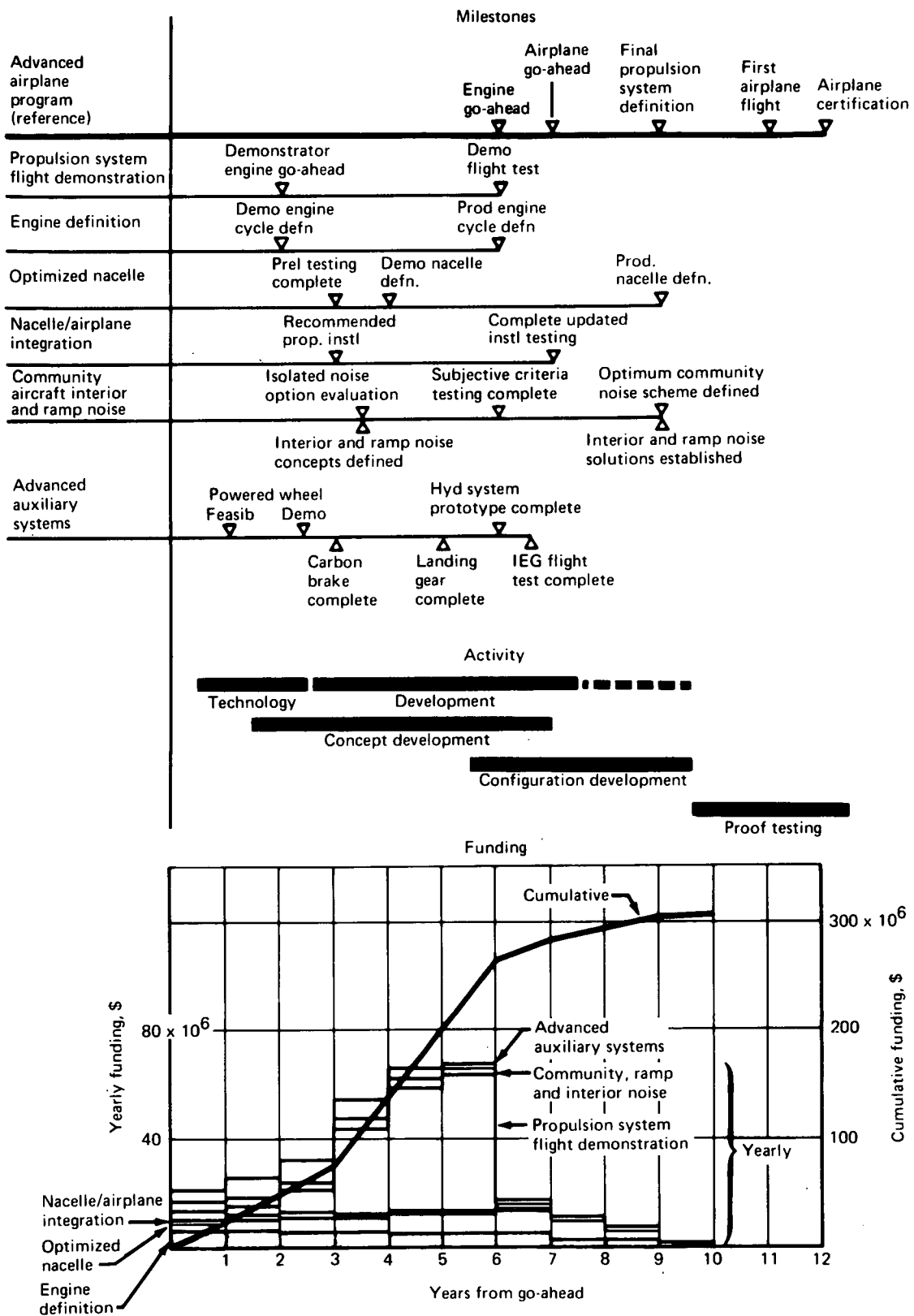


FIGURE 78.— POWER SYSTEMS COST AND SCHEDULE SUMMARY

- In interpreting figure 76, note that the summary noise and performance benefits of the individual programs do not add arithmetically. Reduced weight, for instance, reflected as part of the TOGW reduction, has been identified with a mixed-exhaust nacelle due to possible elimination of the primary airstream thrust reverser. However, this benefit would not be realized if other factors eliminated the mixed-exhaust design from consideration.

In the sections that follow, the potential payoff, state-of-readiness, recommended action and cost and schedule of the six major subprograms of figure 76 are described.

Propulsion System Flight Demonstration

Potential Payoff

The objective of this element of the Power Systems program is to validate that a satisfactory design of an integrated propulsion system, which meets or exceeds the identified noise and performance goals, has been achieved. This program, together with the design technology leading to it, provides the basis for commitment to a production engine go-ahead. The objective will be accomplished by integrating, in an optimum manner, the propulsion system design considerations illustrated schematically in figure 79. This is more fully discussed below and in the three sections that follow: Engine Definition, Optimized Nacelle and Nacelle-Airplane Integration. The potential payoff would be attainment of the goal for reduction in noise of 8-18 EPNdB relative to today's technology and 3-4% improvement in takeoff gross weight

State-of-Readiness

As a result of work over the past several years, e.g., the NASA Treated-Nacelle Program and the current Quiet Engine Program initiated in 1967 and directed by NASA Lewis, the three new commercial air transports have been designed to lower noise levels than earlier jet aircraft. The widebody jets implement many recent developments and have noise levels below current FAR 36 requirements. The NASA ATT studies indicate that major additional noise reductions will require new approaches with attendant high risks. These circumstances dictate the requirement for a hardware validation program.

Moreover, the nacelle work to date has tended to take a given engine and optimize a nacelle around that engine rather than optimizing the engine and nacelle as a single system. It is clear that some of the design choices of each of these systems interact strongly. For example, the specific design requirements of acoustic treatment within the nacelle and engine will have a strong influence on the propulsion system design. These requirements depend in large measure on the noise source distribution, propagation modes and flow conditions created within the engine and nacelle by the many turbomachinery, combustion, and internal-flow noise generation mechanism. Test results and theory have indicated that if the detailed noise propagation modes from the noise sources could be controlled, or designed for, noise could be much more effectively cancelled or absorbed by acoustic treatment within the engine and nacelle. Some of the known design areas where noise reduction payoffs can be obtained are shown in figure 79. Furthermore, when splitters are employed, the interaction between thermal anti-icing requirements, engine design, reverser design, and accessories design becomes very strong, particularly on a high performance nacelle.

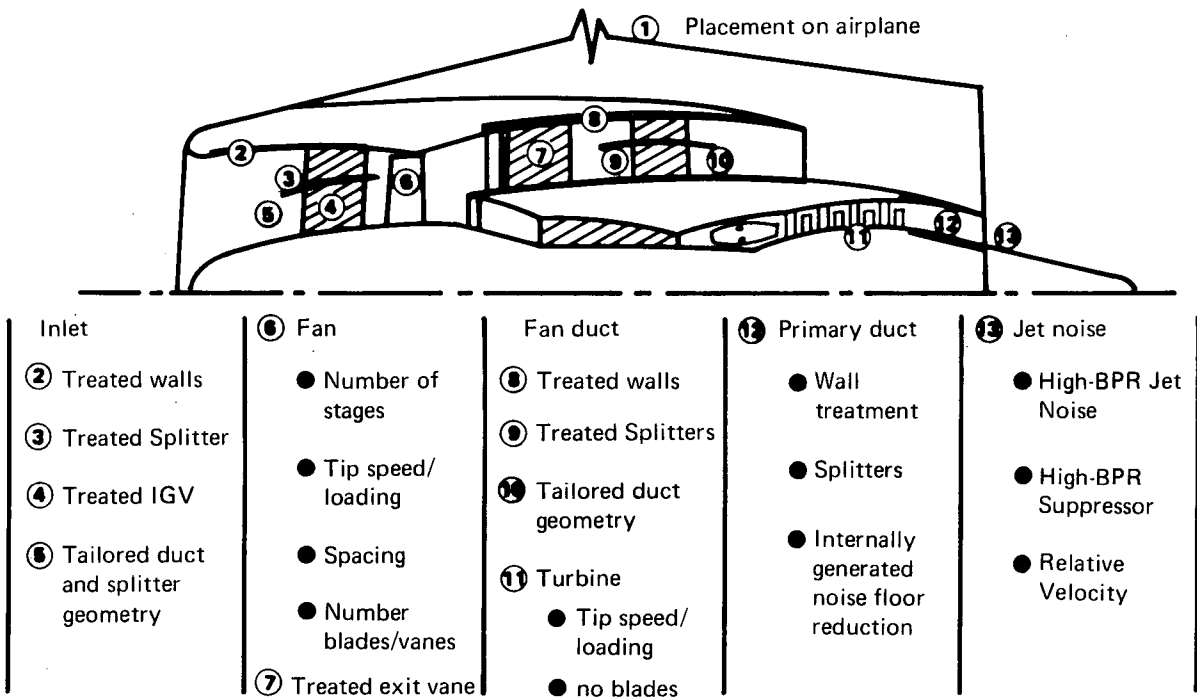


FIGURE 79.—PROPULSION SYSTEM NOISE REDUCTION OPPORTUNITIES

Recommended Action

It is recommended that NASA and the airframe and engine industry jointly develop a flight demonstrator program to provide focus and to validate the achievement of those technology advances described in this and the following three subsections which are deemed to be of particular risk. The program, moreover, would seek to optimize integration of the engine, nacelle and airplane installation technologies and is recommended to consist of the following phases (see figure 80):

- Phase I—Develop propulsion system designs in sufficient depth so that preliminary choices can be made on the key engine and nacelle design variables early in the program, thus minimizing dual developments (e.g., fixed and variable geometry inlets). Trade studies would be conducted to evaluate: a matrix of engines with a range of rotor-stator spacings, chord widths, and tip speeds; introduction of inlet guide vanes, full length fan case splitters, treated exit guide vanes, etc.; the degree of divergence (i.e., expansion) appropriate to the fan nozzle; specific areas of interference between major nacelle subsystems such as the thrust reverser and the acoustic treatment and others. The penalties for installing and anti-icing inlet splitters would be established. Selection of the best engine/nacelle combination which meets the prescribed noise goal would be based on an assessment of overall aircraft payoff reflecting installed weight and performance.
- Phase II—Select and detail design the nacelles for the subsequent ground and flight test; test first engine.
- Phase III—Manufacture three hardware nacelles. Conduct ground and flight test to substantiate: subsystem model and analytical work; total system operation; and, achievement of noise and performance goals.

Cost and Schedule

The cumulative funding total for the demonstrator program itself is estimated to be \$140 million. A breakdown by year is shown in figure 80.

Engine Definition

Potential Payoff.—The objective of this work is to provide definition to those engine design considerations expected to have a major impact on the noise and performance goals of the Power Systems program. Figure 81 illustrates these considerations. A portion of the payoff described below can be achieved if data are developed to permit the best design choices including noise advantages inherent in using inlet guide vanes (IGV's) and selecting the number of fan stages with the associated question of exhaust stream mixing. Also, modest gains in noise reduction are identified from improved engine design due to: improved identification of turbomachinery noise sources; advances in understanding scaling factors; and, advanced design approaches such as blade surface flow control. Even small improvements in jet noise can provide benefits since higher-than-optimum bypass ratios are currently being selected in order to minimize jet noise floors. These will stem from improved understanding of jet noise sources and relative velocity effects and from improvements in jet suppressor design.

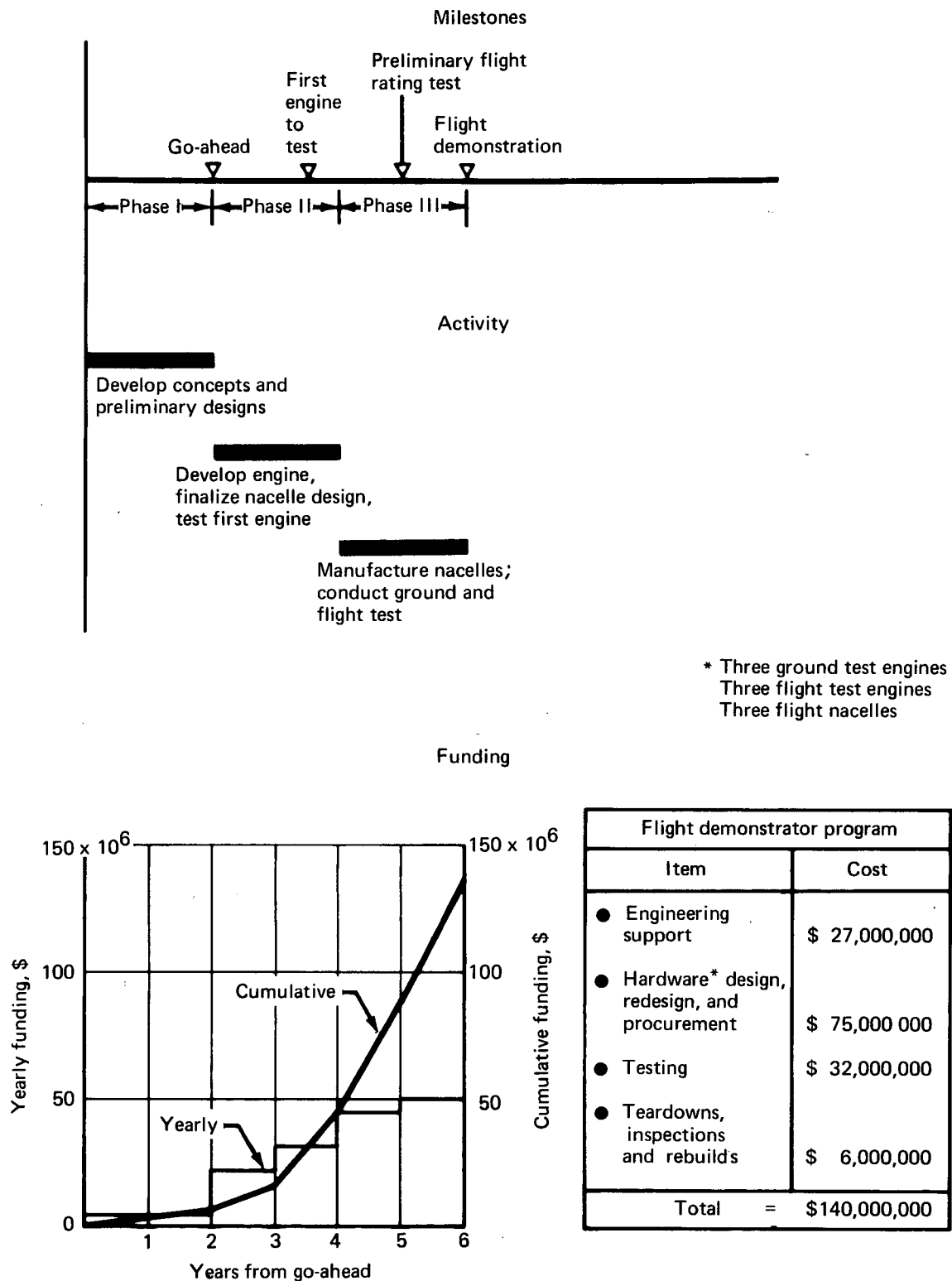


FIGURE 80.—PROPULSION SYSTEM FLIGHT DEMONSTRATION

Objective: Define implication of engine definition

Payoff: 2% TOGW, 3-8 EPNdB

R & D Dollars: \$50 Million + Engine technology development

Considerations: Fan stage noise, mixed/unmixed exhaust, engine source noise, and improved F_N/W

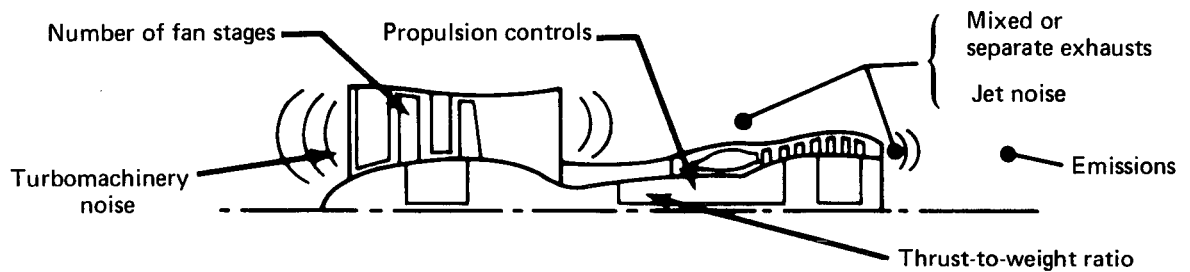


FIGURE 81.—

FIGURE 81.—ENGINE TECHNOLOGY DEVELOPMENT AND SOURCE NOISE
REDUCTION OPPORTUNITIES

Benefits in the area of propulsion controls will stem from: the use of modern control theory and improved dynamic engine simulation; more fully integrated designs; and, from enhanced use of electronics and digital computation. These benefits include performance improvement due to closer-tolerance control systems; optimum utilization of installed power; and, extended engine life. Other benefits are foreseen in the areas of reduced crew workload, reduced control system development costs and reduced engine maintenance.

The potential payoff would be attainment of the goal for reduction in noise of 3-8 EPNdB and 2% in takeoff gross weight.

State-of-Readiness.—The question of 1 and 2 stage fans and/or the consideration of whether to mix the exhaust streams is currently unresolved and the subject of continuing government and industry study. For example, the Phase II ATT candidate engines include one single-stage engine with mixed-exhaust and one two-stage, with separate exhaust. This latter study will help shed additional light on the situation. However, it is clear that additional test data must identify either direct or indirect noise advantages associated with the number of fan stages. This must be based on improved understanding of fundamental noise sources and their detailed propagation modes. Existing data suggest that improved noise control could then be effected. Furthermore, improved data associated with the penalties of mixing the exhaust streams of high bypass ratio engines is needed. Other aspects of the mixed-exhaust concept, such as the possible elimination of a primary thrust reverser need further study.

In the past, engine IGV's have been removed with direct benefit to turbomachinery noise generation. More recently, model data have shown that properly located IGV's may actually provide noise benefits relative to the no-IGV case. It is necessary to confirm this data and to develop improved understanding of the effects on the rotor vector diagram by tests of larger scale hardware. Concerning the exhaust system, studies are currently being conducted under the Department of Transportation to design and evaluate the feasibility of a suitable jet suppressor for economical retrofit of the JT8D engine. This program is expected to demonstrate some improvements in suppressor technology; however, it remains to be shown that similar improvements can be obtained for the low jet velocity, higher bypass cycles envisioned for an advanced technology transport.

Propulsion controls requirements have steadily become more severe in order to improve aircraft safety and to achieve high engine efficiency. Present controls are primarily hydro-mechanical and limited in scope and capability. Improved engine instruments may allow better thrust setting and performance monitoring than in the past; rudiments of auto-thrust management have been introduced; and analytical tools for propulsion control design have been improved. The feasibility of control integration and propulsion control by digital computer have been experimentally demonstrated, but the crew work load arising from power plant control remains high and the potential benefits have not been obtained with existing systems, often because the controls development was not introduced early enough into the engine and airframe process.

Recommended Action.—A three phase program involving airframe and engine contractor efforts is recommended as described below and in figure 82. The initial phase of this program should be directed totally at the demonstrator engine definition. The later phases are directed toward commitment to the assumed production airplane.

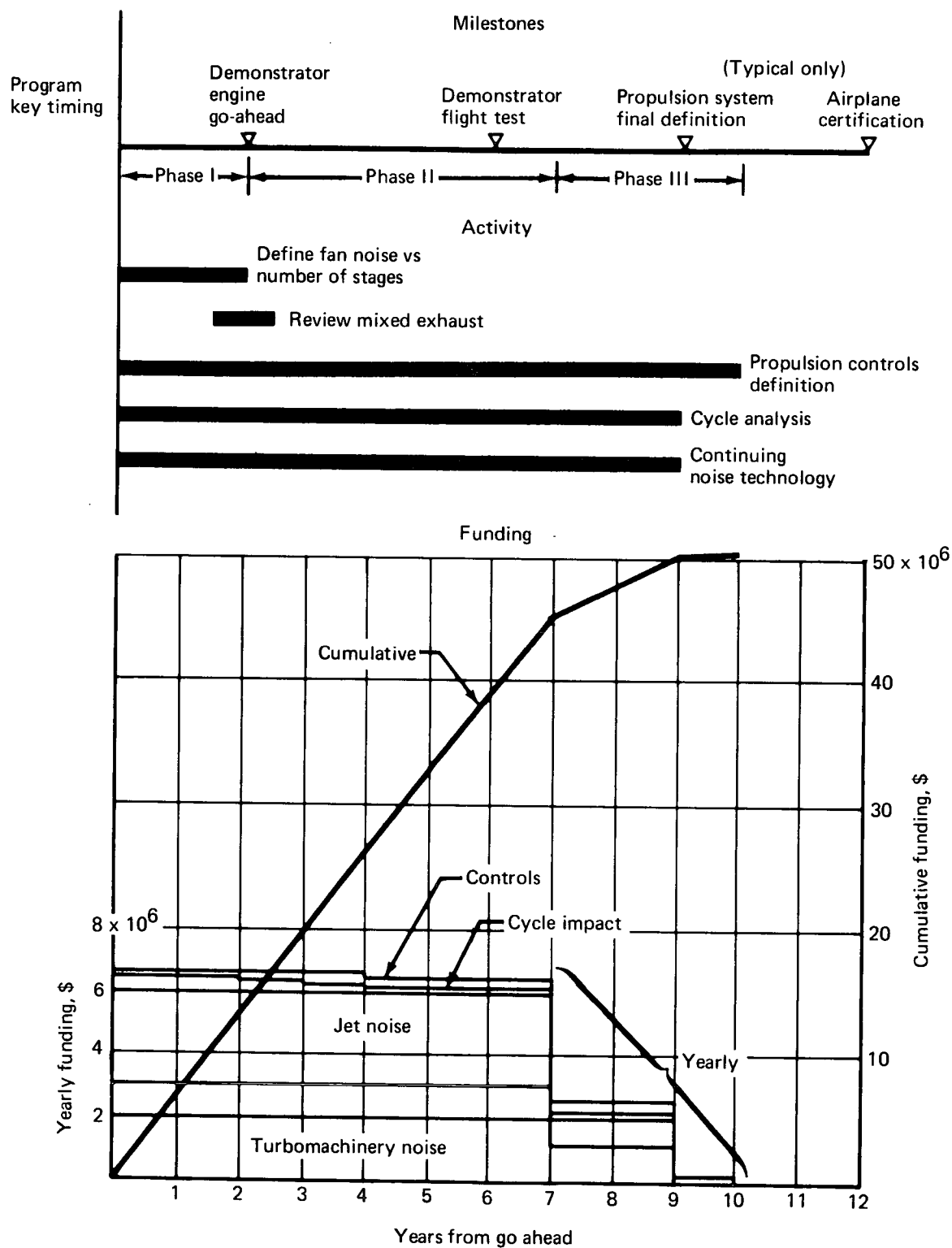


FIGURE 82.—SCHEDULE—ENGINE DEFINITION

- Phase I—Cycle evaluation and engine-airplane matching studies would be conducted to provide the best basis for selecting the demonstrator engine. Bare engine data for a matrix of engines would be developed by the engine manufacturer. Coordination with the airframe manufacturer would be maintained so that the effects of engine configuration and installation losses can be assessed to mutual satisfaction. Existing, computerized thermodynamic cycle analyses would be employed. Specific attention should be given to integral engine design considerations which directly impact source noise and mode propagation—such as: fan tip speed and blade loading; rotor-stator spacing, blade number, turbine and combustor design and treatment of internal engine surfaces. Early noise and performance data developed from subsystem testing would be used to establish: the number of fan stages, bypass ratio, mixed or unmixed exhaust, the use of IGV's, etc. Preliminary assessment of propulsion controls requirements will be made.
- Phase II—As shown in figure 78, completion of the demonstrator engine flight test would initiate a go-ahead for the production engine of the advanced transport airplane. These recommended Phase II efforts span an estimated 5 year interval during which continued turbomachinery and jet source noise technology development, improved concept definition of engine layout, additional configuration study and evaluation of the demonstrator program would be accomplished. These efforts are all compatible with the overall schedule and are expected to benefit the advanced transport airplane.
- Phase III—A reduced but continuing effort is shown for Phase II. Innovations in jet or turbomachinery noise technology which do not have a major impact on the propulsion system or airplane design can still be applied to an assumed airplane during this period. Efforts in the software area of propulsion controls should continue and are recommended to extend even slightly beyond the final propulsion system definition.

Cost and Schedule.—The cumulative funding total for the engine definition efforts is estimated to be \$50 million. A breakdown by year and subprogram is shown in figure 82.

Optimized Nacelle

Potential Payoff.—The objective of this program is to provide the fundamental basis for a nacelle design which achieves the performance and noise goals identified below. Improvements to the nacelle (see figure 83) are anticipated in the inlet, exhaust system, thrust reverser, acoustic treatment and accessories subsystems.

Inlet improvements have been evaluated on the basis that additional effort would validate an inlet concept which avoids takeoff doors. Other benefits can be realized in weight and cowl-wetted-area drag provided that a shorter fan cowl can be developed which is compatible with thrust reverser and cowl drag rise constraints. Internal fan duct losses can be reduced if smaller accessories, improved internal arrangement, or a modest external "bump" can be introduced at small penalty. Improvements in the acoustic lining are anticipated from 2 separate considerations: 1) improved design methods such as incorporation of boundary layer refraction effects; and 2) optimized ring and splitter placement within the nacelle. At the

Objective : Develop optimized nacelle configuration
 Payoff : 3% TOGW; 6-15 EPNdB
 R & D Dollars: \$47 million
 Considerations: Inlet, exhaust system, accessories, thrust reverser, and acoustic treatment

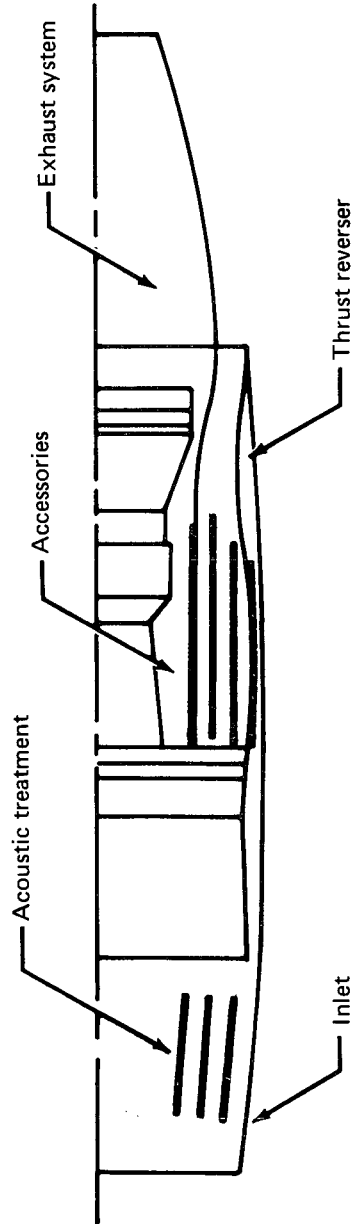


FIGURE 83.—NACELLE TECHNOLOGY DEVELOPMENT OPPORTUNITIES

exhaust-end of the nacelle, savings are identified by optimizing the boattail pressure drag associated with nacelle closure. Internal nozzle improvements are foreseen for a convergent-divergent fan nozzle optimized between cruise and takeoff performance. Maintenance savings for improved thrust reverser designs and reliability are expected to show significant benefits in terms of reduced operating costs. In some circumstances, significant weight savings can be identified provided the primary thrust reverser can be replaced by a thrust spoiler or perhaps done away with entirely. The potential payoff would be attainment of the goal reduction in noise of 6-15 EPNdB and 3% in takeoff gross weight.

State-of-Readiness.—NASA contractors have completed parametric trade studies on several candidate inlet, fan cowl and nozzle configurations suitable for near-sonic nacelles under the current ATT contract. The absence of test data prevented some of the more innovative nacelle subsystem designs from being evaluated. Moreover, an inlet design with satisfactory noise qualities and suitable low and high speed performance has not yet been achieved. One high priority task is the evaluation of fixed geometry (i.e., high contraction ratio) inlets. If reasonable cruise drag-rise properties for such inlets can be established at an early date, then a great deal of effort devoted to variable-takeoff-geometry designs can be eliminated. Preliminary cowl drag tests have been run both within industry and NASA; however, insufficient high contraction ratio models have been studied. A recommended cowl drag test has been formulated and is described further in the Aerodynamic Configuration section.

Additional test data and improved analysis and design techniques are required in the exhaust system. Data exists for Mach numbers and pressure ratios appropriate to powerplants for the 747, DC-10, L-1011. However, the advanced aircraft will be at higher Mach numbers and pressure ratios perhaps as high as 3.5 to 4.0. NASA has developed a good deal of transonic exhaust system data, but this has largely been applicable to the transonic mission leg of the SST and the turbojet nacelle geometries are generally not appropriate to the bypass ratios suitable for a near-sonic design point airplane

Increased emphasis on noise requires a re-evaluation of the traditional approach to nacelle configuration. For instance, use of an aft-fan cowl-mounted thrust reverser tends to restrict the placement of splitters in the fan duct. The contractor currently is reviewing and systematizing thrust reverser design information under contract with the Air Force. However, it is necessary to review current thrust reverser requirements and define and evaluate innovative design concepts in this light. Current industry-wide understanding of the effects of nacelle geometry on propulsion noise is limited at best. A coordinated program to evaluate this aspect of nacelle design is necessary.

Recommended Action.—A two-phase program to be sponsored by NASA and conducted by airframe industry contractors with engine contractor coordination is shown in figure 84 and is discussed below.

- Phase I—This phase would consist of model testing to evaluate alternate design concepts which impact the demonstrator engine selection: e.g., fixed or variable geometry inlet; fan reverser external to fan cowl; etc. Specific efforts to be undertaken would include:
 - INLET—design and mechanical evaluation of a flexible lip inlet, water table and compressible flow analysis of advanced boundary-layer-controlled inlets,

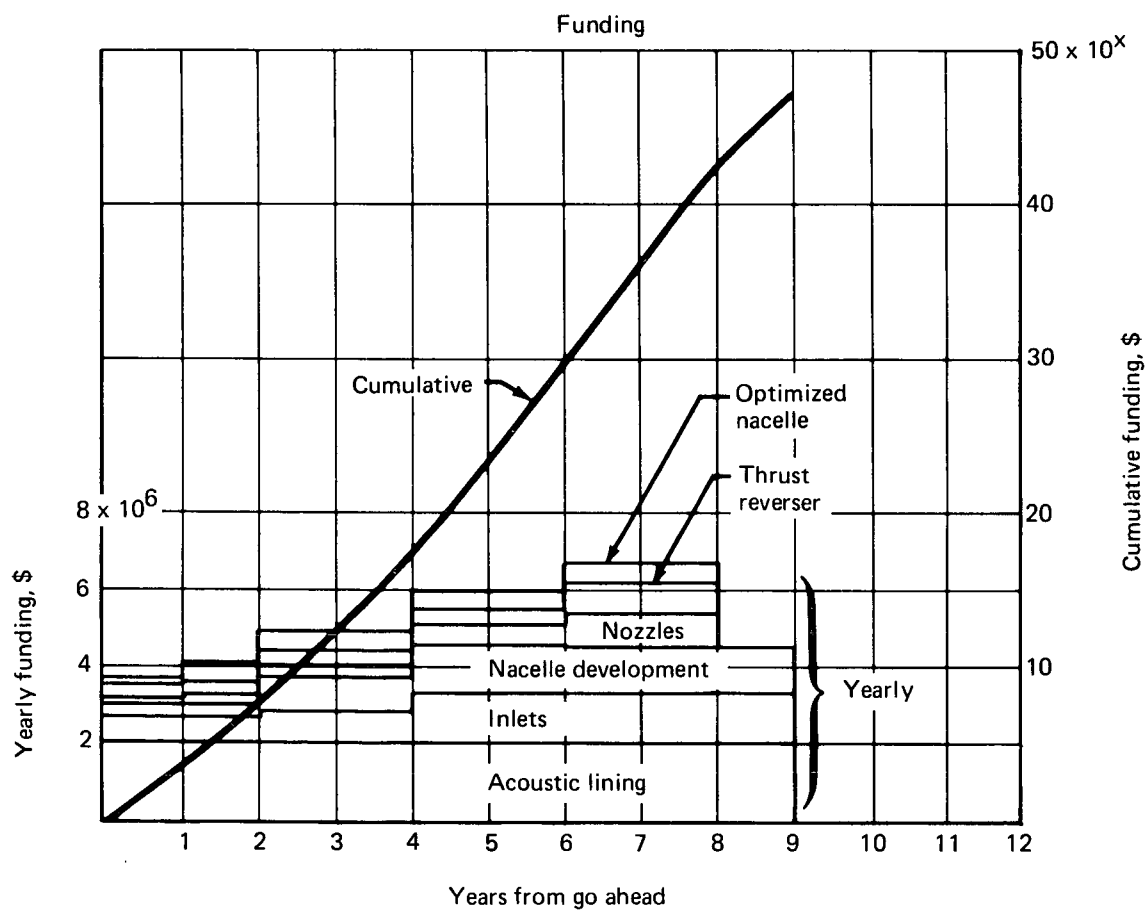
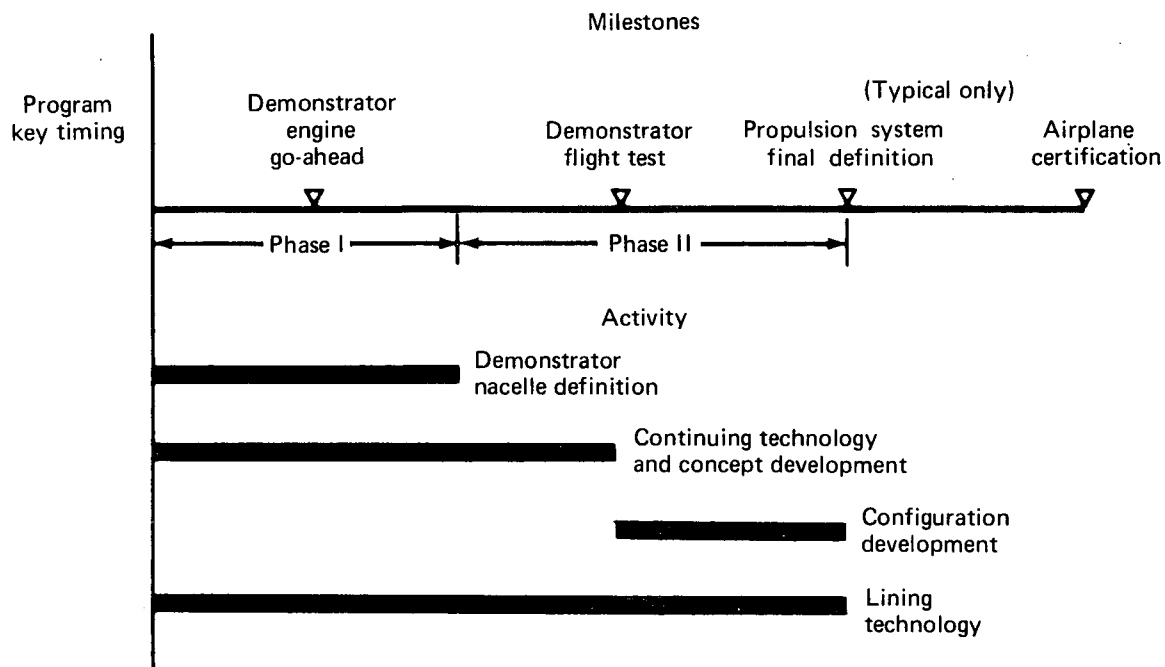


FIGURE 84.—OPTIMIZED NACELLE

model noise rig evaluation of the noise penalty of auxiliary takeoff doors, preliminary evaluation of engine-inlet compatibility for candidate inlet concepts

- EXHAUST SYSTEM—improved analysis of the mixed subsonic/supersonic flow field of the nacelle afterbody cowl, optimization of a fixed geometry convergent-divergent fan nozzle, development of additional scrubbing drag data for shallow angle plug nozzles
- THRUST REVERSER—basic data enabling design for improved flow control would be developed, innovative reverser designs which minimize conflict with internal acoustic treatment would be defined and evaluated, and basic design requirements would be reviewed to enable reversers which can provide maneuvering power for airplanes in all taxi conditions and which would, moreover, markedly improve current design reliability and maintainability
- NACELLE TREATMENT—potential design improvements including consideration of boundary layer effects and source noise modal distribution would be evaluated, the trades between active and passive lining concepts would be assessed, optimization of treatment location would be studied both analytically and experimentally in model fan test rigs
- ACCESSORIES—design advances in miniaturized pumps and nacelle space savings effected through the use of the internal engine generator would be identified and evaluated, and the merits of “chin-mounted” accessories as opposed to the current use of a fan duct bifurcation would be reviewed in the light of further cowl drag testing.

The above individual considerations and testing should be given focus by continuing design studies of the propulsion subsystems and the overall nacelle using one or more baseline study engines made available from the engine manufacturers. Improvements in integral acoustic lining designs and increased understanding of the effect of fan/primary nozzle geometry on noise propagation would be developed.

- Phase II—Since the demonstrator program, which would develop three duplicate nacelles, cannot satisfy the total large scale testing needs, it is constrained to considerations for which decreased risk is deemed mandatory prior to an airplane program go-ahead. Therefore, additional technology and concept development is recommended to proceed in parallel to the demonstrator program. These latter efforts would involve continuing evaluation of innovative inlets, exhaust system closure drag optimization, thrust reverser weight reduction, and advanced acoustic treatment designs as identified specifically above for Phase I. The scope of design concepts would be narrower than in Phase I and emphasis on design and test should be increased. This work would provide additional and updated technical data required for the assumed airplane program go-ahead decision.

Cost and Schedule.—The cumulative funding total for the optimized nacelle R&D efforts is estimated to be \$47 million. A breakdown by year and subprogram is shown in figure 84.

Nacelle/Airplane Integration

Potential Payoff.—The objective of these efforts is to establish the proper integration of the propulsion system into the airplane configuration in order to achieve the noise and performance goals identified below. Portions of the work described in this section are intended to be accomplished jointly with efforts described in the Aerodynamic Configuration section.

Noise benefits are anticipated through better understanding of engine placement effects on noise production and propagation. For example, the placement of inlets and/or exhausts adjacent to acoustically shielding aircraft surfaces or flow fields (e.g., overwing engine installation) has been shown to be beneficial. Also, weight savings of 1,000 pounds per nacelle can be envisioned if nacelle installations are located so that the engine mounts are close to main structural spars.

Other possible nacelle/airplane integration benefits include: improved landing and take-off characteristics by using the propulsion system to provide increased and controllable lift; and, improved efficiency from integration of the thrust reverser into high-lift devices. The potential payoff would be the attainment of goals for reduction in noise of 2-4 EPNdB and 1% in takeoff gross weight.

State-of-Readiness.—Propulsion integration analysis and wind tunnel testing have been developed within NASA and industry in support of previous airplane programs in order to achieve improved performance. Simulation of nacelle intakes on wind tunnel models is usually accomplished by using flow nacelles in which the nacelle exit area is sized to provide the proper intake mass flow ratio. Wind tunnel simulation of the proper engine exhaust conditions is much more difficult. Three possible simulation techniques which have been studied analytically and experimentally have been: 1) the blown nacelle with capped intake, 2) ejector nacelle using external high pressure air, and 3) turbo-powered nacelle using external high pressure air. Each of these has limitations and choice of the propulsion system simulation for evaluating near-sonic cruise design point aircraft will need substantial care. Certain airplane configurations such as those with engine placement resulting in overwing exhaust need particular attention.

The shaded area of figure 85 shows the range of perceived noise levels for four different airplanes which use the same basic engines. The reasons for these differences are not completely understood, but they are believed to be caused by different nacelle configurations and engine placement effects. Theoretical acoustic analysis and empirical data have shown that reductions in far field noise are achievable if the engine is properly shielded; however, additional experimental effort is required before the effects can be satisfactorily quantified. Moreover, the experimental techniques themselves need development before these differences can be understood.

Recommended Action.—Joint efforts by NASA and the engine and airframe contractors are recommended in 2 phases as shown in figure 86 and described below. Phase I is pertinent to the flight demonstrator program; Phase II supports a decision for commitment to production.

Objective: Develop nacelle/airplane integration with noise advantages
Payoff: 1% TOGW; 2 - 4 EPNdB
R&D Dollars: \$5.0 million
Considerations: Unconventional placement, nacelle configuration, and noise shielding

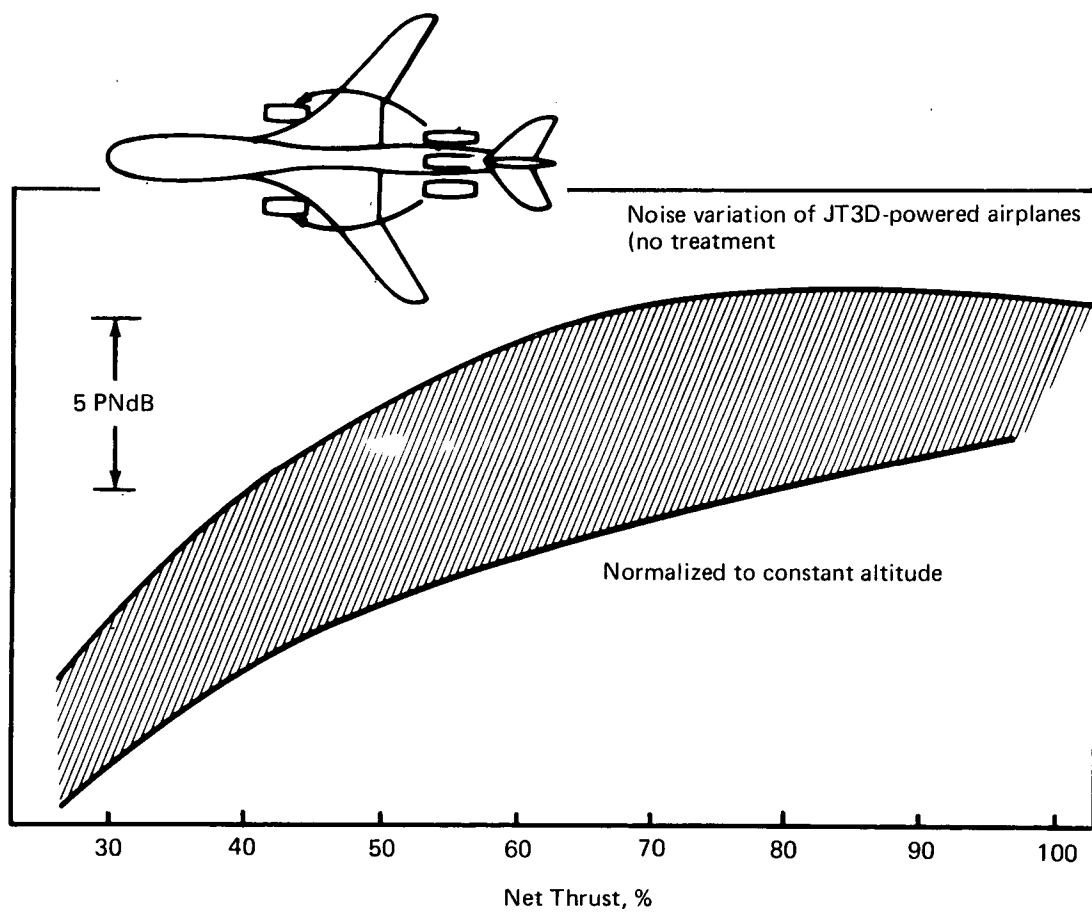


FIGURE 85.—POSSIBLE IMPROVEMENTS WITH BETTER UNDERSTANDING OF INSTALLATION GEOMETRY

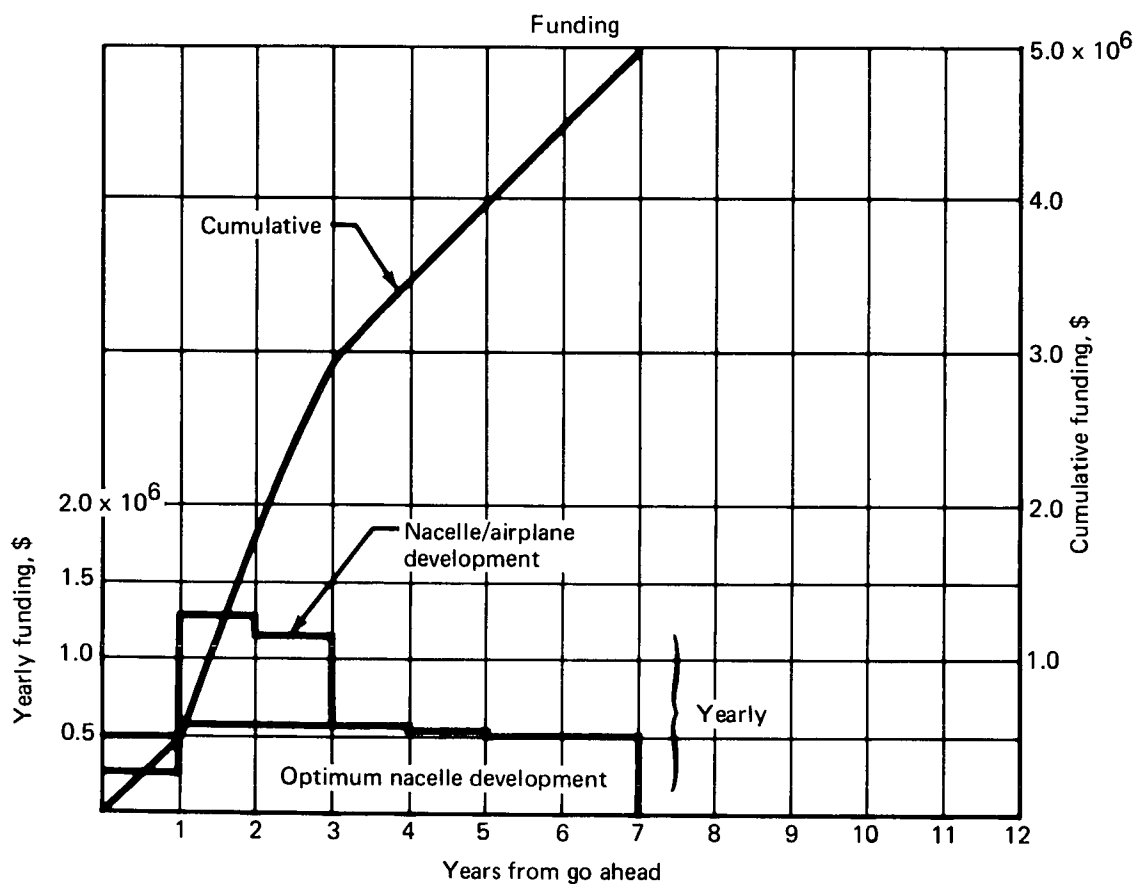
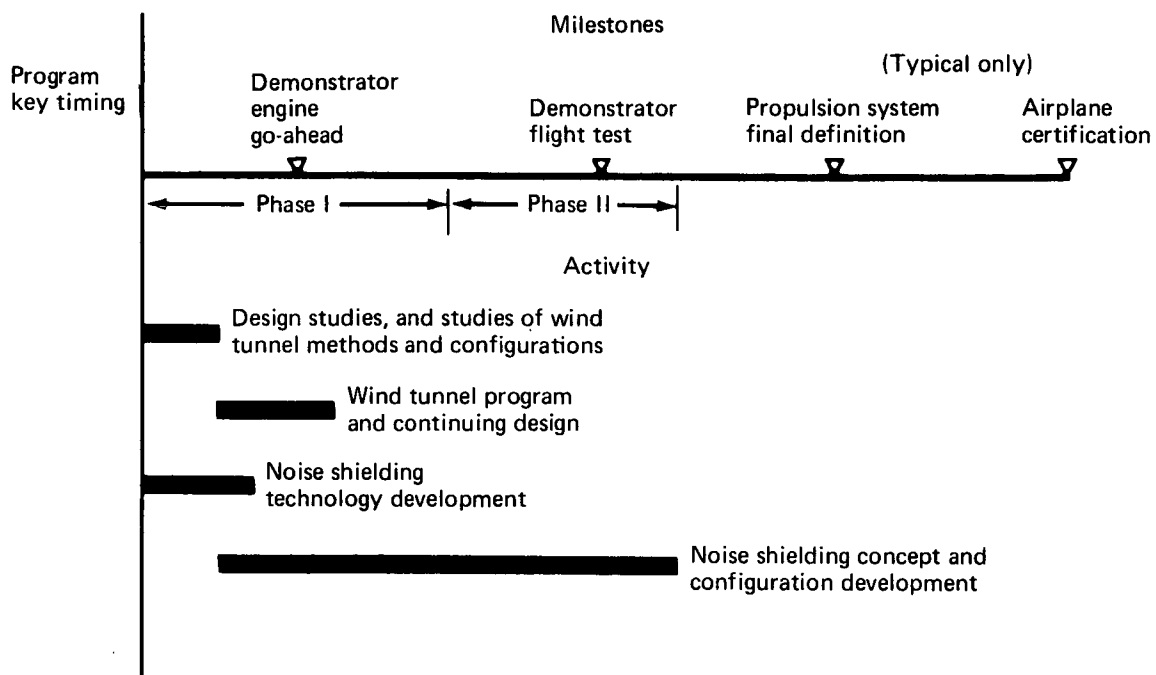


FIGURE 86.—NACELLE/AIRPLANE INTEGRATION

- Phase I—The initial work would help identify the airplane configuration in order that the subsystem work be accomplished in an installation appropriate to the demonstrator program; this work should include: 1) utilization of applicable analysis techniques for propulsion integration, 2) design studies to assess relative weight and performance of various propulsion placements and installations, 3) studies of the integration of the thrust reverser and airplane configuration, 4) review and evaluation of suitable wind tunnel propulsion simulation techniques, 5) preliminary wind tunnel testing with flow nacelles.

Early studies of the effect of engine placement on noise attenuation must also be undertaken in Phase I. These should include extensions of current theoretical methods and studies of improved acoustic testing techniques. Specific installations and placement effects to be considered would be: overwing pod, slipper nacelle, wing-buried engines, fore and aft nacelle position. In addition, the geometry of the nacelle itself, as discussed under the Optimized Nacelle heading, will be considered in conjunction with the placement aspects of nacelle-airplane integration. It is intended that each design be reviewed with respect to suitable aerodynamic, flight control and structural constraints. This effort will be coordinated with those described in the Optimized Nacelle section. Small scale testing to verify design techniques and indicate optimum airplane configurations from acoustic considerations would be conducted. Design studies conducted in parallel to the testing would provide the basis for evaluating competitive configurations.

- Phase II—Efforts in Phase II would be technically similar to those in Phase I but would be directed towards specific details of a reduced number of configurations. A few of the nacelle/airplane configurations would be chosen for wind tunnel testing. The most favorable of these models would be modified and tested to provide a firm basis for commitment to production of the preferred nacelle/airplane configuration for the advanced transport aircraft.

Cost and Schedule.—The cumulative total funding for the nacelle airplane integration efforts is estimated to be \$5 million dollars. A breakdown by year and subprogram is given in figure 86.

Community, Aircraft Interior and Ramp Noise

Development of various approaches to aircraft noise reduction is recommended in the previous Propulsion System Flight Demonstration section and the Powered Wheel section that follows. These include reduction of engine source noise, alterations to installation geometry, improvements in acoustic treatment and innovations in aircraft ground operating procedures. A comprehensive community noise program must also consider such factors as noise abatement flight procedures; airport traffic control; airport/community land use planning; and improvements in the technology of community noise assessment. Additional material concerning the first two of these factors will be found in the Control of Flight discussion. The synthesis of these noise reduction options into an overall community noise program is the work described in this section.

Improvements in aircraft near-field (ramp) noise and in passenger noise environment, both on the ground and in flight, are included in this recommendation.

Potential Payoff

The development of accurate appraisals of community noise exposure and the public response to noise will permit determination of a minimum cost method for obtaining a compatible community noise environment. A noise reduction payoff of 5 EPNdB at the FAR Part 36 approach control point is anticipated from revised flight procedure efforts. Reduction of aircraft interior noise levels will improve passenger appeal and reduction of ramp noise levels will achieve a more acceptable environment for ground service crews and boarding passengers.

State-of-Readiness

Aircraft community noise has become a major constraint to the future growth of air transportation. The increase in community noise associated with jet aircraft has increased public reaction to noise and resulted in opposition to airport operations and expansions. Maximum allowable noise levels have been adopted for new aircraft certification and for aircraft operation at many airports. However, the three FAR 36 control points do not adequately describe the community environment. Figure 87 illustrates a flight procedure which will result in reduced community impact of noise but does not change the noise levels at the three control points. Various subjective noise units have been developed as criteria of community acceptability but so many factors are important in the response of people to noise that all of these criteria involve considerable oversimplification. A more comprehensive community noise criteria, e.g., an area footprint coverage relative to actual land use could be the basis for a more detailed community noise assessment and the establishment of a consistent land use profile for all airports.

Government and industry have begun to reduce the impact of noise on communities by modification of flight profiles, airport curfews, expansion of airport boundaries and the use of new propulsion systems designed for reduced noise. Much more must be done to achieve acceptable aircraft noise outside airport boundaries and to determine what design goals should be established for future airplane designs.

Awareness of noise has extended to the passenger cabin during both airplane cruise and ground operations and to ramp noise at ground crew service locations and passenger loading areas. Any major reduction in propulsion system noise will raise expectations of improvements in aircraft interior noise and ramp noise. Design approaches leading to lower source noise levels from auxiliary power units and air conditioning packs should be defined. The use of treated air inlet and outlet ducts require study. The location of these units and the orientation of duct outlets have a major influence on the magnitude of the noise problem at crew service locations and passenger boarding ramps.

Objective: Systems analysis to determine acceptable community, aircraft interior, and ramp noise environments

Payoff: Public acceptance of air transport operations ; 5EPNdB

R & D Dollars \$23 million

Considerations: Review current criteria and determine minimum cost solutions

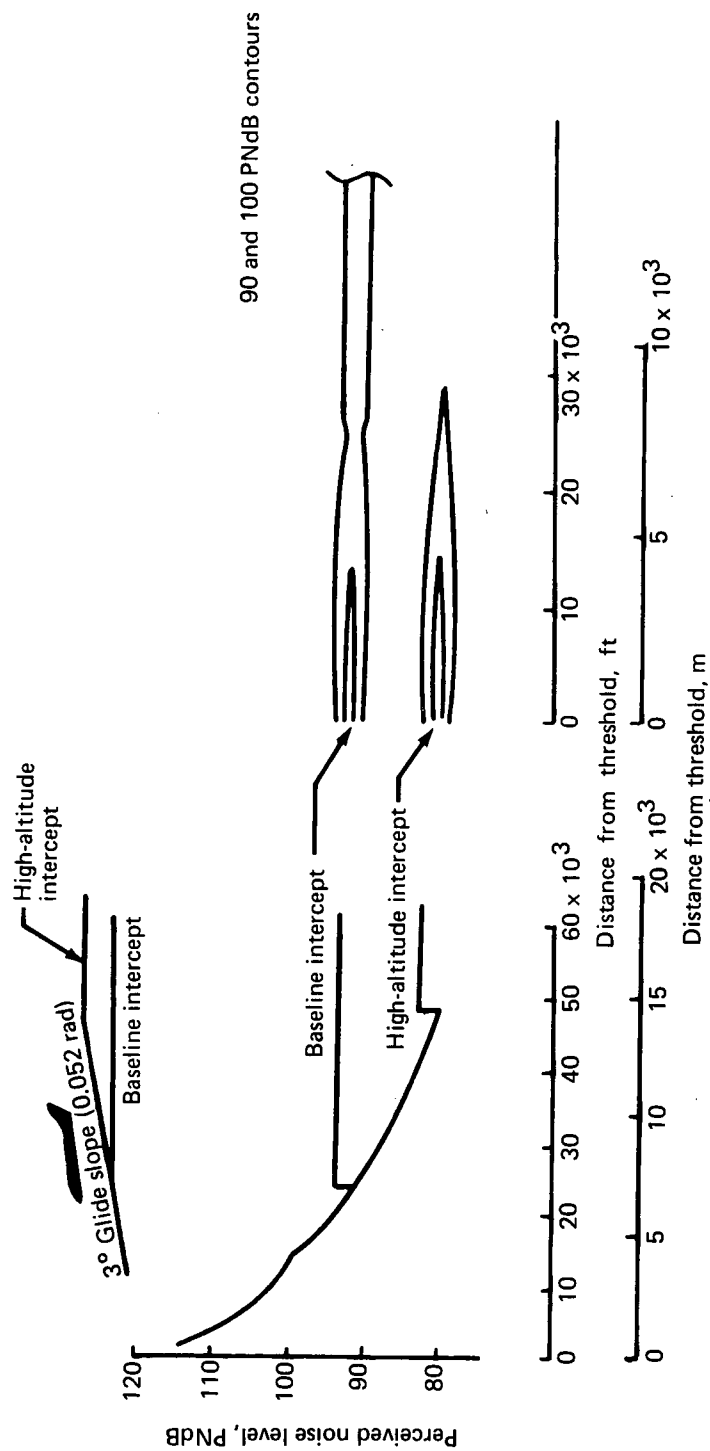


FIGURE 87.—COMMUNITY NOISE IMPACT REDUCTION DUE TO REVISED FLIGHT PROCEDURES—FAR 36 REFERENCE NOISE LEVELS REMAIN UNCHANGED

Recommended Action

The efforts prescribed for this recommended program are discussed separately in terms of defining: 1) a synthesis of community noise solutions and 2) solutions to improved aircraft interior and ramp noise.

A three-phase community noise technology program is recommended to be conducted by the engine and airframe manufacturers. It is recommended that NASA act as a coordinator for contributing efforts which should also be pursued by the government regulatory agencies, representatives of the airport authorities and the airline industry. The program is shown in figure 88 in three phases:

- Phase I—Subjective criteria for assessment of community noise would be established by laboratory and field tests of selected noise juries. Subjective noise measurements would be developed for each class of aircraft noise to ensure that selected noise reduction options will be discernible by the public as beneficial and to minimize the cost of hardware changes required for a given noise reduction. Differences in noise character, from that currently experienced, due to the innovation of various noise suppression techniques including nacelle treatment and flight operational procedures, would be evaluated. It is planned to analyze human responses and statistically evaluate this data as the basis for developing the desired criteria.

In parallel to this effort, the initial step in developing a synthesized community noise reduction program would be made. This step would define the cost effectiveness of various noise reduction options, such as: engine source noise and treatment benefits; aircraft flight operational procedures; limitations to airport vicinity land use; and improved air traffic control systems. These studies will establish the costs associated with achieving increasingly restrictive noise goals. Evaluation of reduced engine and nacelle noise would draw on results of the current NASA ATT studies. In addition, flight tests to evaluate innovative operational procedures would be conducted.

- Phase II—Development of the subjective noise criteria would be continued through Phase II and would culminate and be coordinated with the optimized propulsion flight demonstration described previously. Step 2 of the community noise synthesis program is intended to evaluate four specific alternate solutions to the community noise problem. The four alternative methods would be formulated based upon conclusions drawn in Step 1 concerning the noise reduction options. It is anticipated that the four alternatives studied would be composites of these options. A systems analysis approach will be employed to establish for each alternative: incremental noise gains from each option; costs to the airline and costs to the taxpayer. It is planned to analyze several airports in this way in order that differences in local topography and land use can be established. The demands made by each solution alternative in restricting aircraft design flexibility would also be defined.

- Phase III—Step 3 of the community noise synthesis program would identify and evaluate an optimum solution based upon the four alternative approaches assessed in Step 2. This solution is intended to be airport-independent to the maximum possible degree, in order that any aircraft may use any airport. A plan of action including necessary legislative or regulatory agency rule changes, airport design modifications and aircraft design modifications would be defined for the optimum solution selected. The associated costs of these efforts would be established simultaneously.

The program to develop concurrent improvement of aircraft interior and ramp noise is also described in three phases as shown in figure 88.

- Phase I—The reduction of aircraft interior and ramp noise levels would be pursued in several areas. In an initial concept development phase the following techniques of achieving improved transmission loss would be studied: designs of fuselage structure, window, and door seals; increased insulation effectiveness; and greater acoustic absorption in the passenger compartment. Techniques for reducing radiation by air distribution systems and other equipment would be developed to achieve acceptable noise levels during airplane cruise. Design approaches leading to lower source noise levels from auxiliary power units and air conditioning packs would be defined. The location, orientation and acoustic treatment of air inlet and outlet ducts would be defined.
- Phase II—In this phase several configurations of aircraft systems would be evaluated for improved interior and ramp noise levels.
- Phase III—An integrated design for reduced interior noise would be defined. The best approach to ramp noise which balances onboard noise reduction means with ground protection systems would be formulated in detail based upon the assessments of Phase II.

Cost and Schedule

The cumulative funding total of this program is estimated to be \$23 million. A breakdown by year and category is given in figure 88.

Auxiliary Systems

Potential research and development activities in the auxiliary systems are grouped into eight categories:

- Hydraulic Power Generation, Distribution, and Control
- Advanced Electrical Systems
- Internal Engine Generator
- Landing Gear Systems

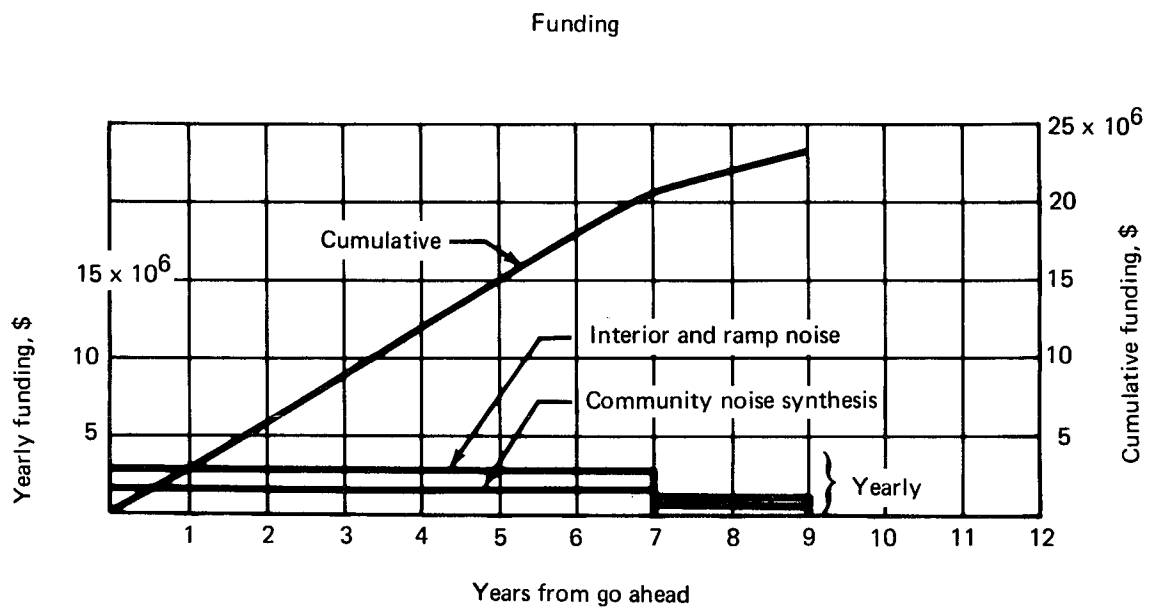
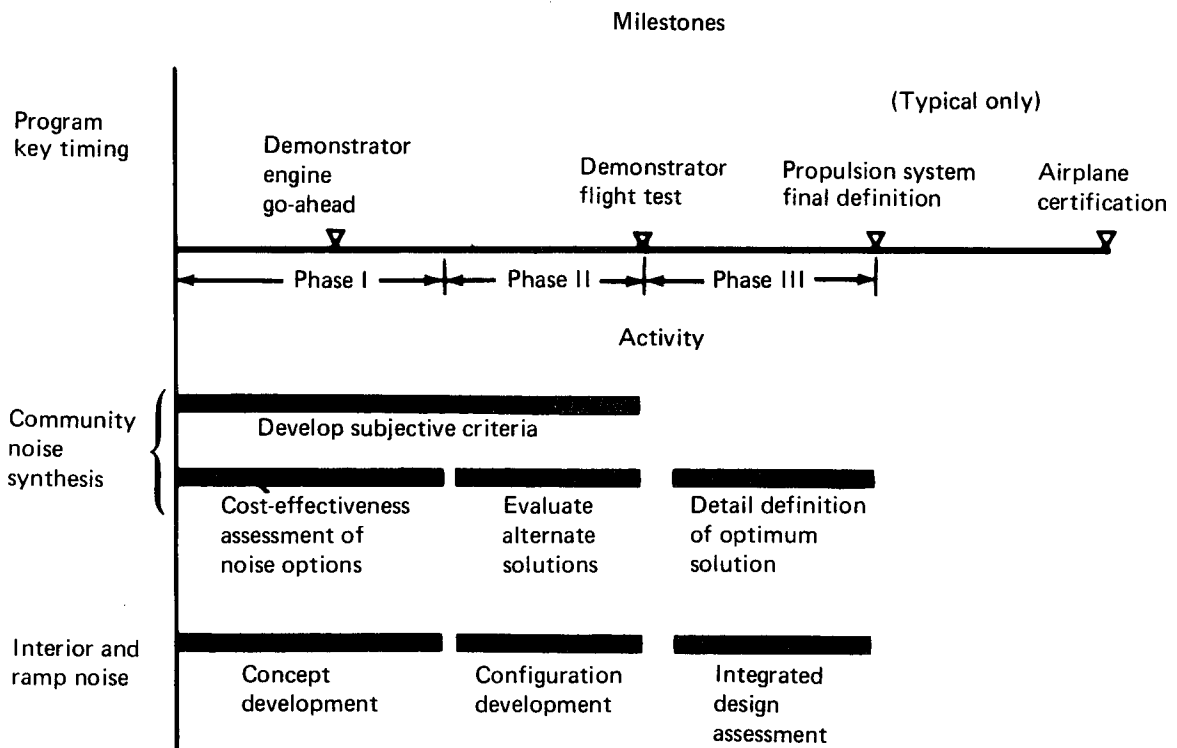


FIGURE 88.—COMMUNITY, AIRCRAFT INTERIOR AND RAMP NOISE

- Structural Carbon Brake
- Powered Wheel System
- Pneumatic, Conditioning and Protective Systems
- Fuel Systems

Maximum benefit can be achieved by completing all the programs discussed herein. However, certain elements are considered to command a priority. High priority programs that could be conducted independently and that should yield positive results are:

- Hydraulic Control Valve Erosion Reduction
- Internal Engine Generator
- Brake Squeal Elimination
- Carbon Brake
- Powered Wheel
- Cabin Air Recirculation

A significant portion of the research and development activities outlined herein reflect the status of work on Contract NAS 1-10893, "An Advanced Concept Secondary Power System Study for an Advanced Technology Transport Aircraft." They are included to provide continuity and to establish proper priorities relative to proposed programs in other technological areas. (See figure 89.)

The programs recommended for NASA funding would require up to 6.5 calendar years to complete and a total funding of 35.8 million dollars (see figure 89).

Hydraulic Power Generation, Distribution, and Control

Potential Payoff.—Significant payoff could be achieved by selected research and development activities in hydraulic systems. A potential reduction of up to 780 lb (353 kg) in system weight is expected. This savings is equivalent to a cycled reduction of TOGW of 0.5%.

In addition, substantial benefits in terms of initial cost and maintenance savings are possible. Savings of \$19,000 per airplane in initial costs and \$17,000 per year per airplane in maintenance are expected. Reduced nacelle size, improved maintainability, and improved system reliability would be achieved.

State-of-Readiness.—The status of the proposed research and development activities in hydraulic systems can be described in four basic categories.

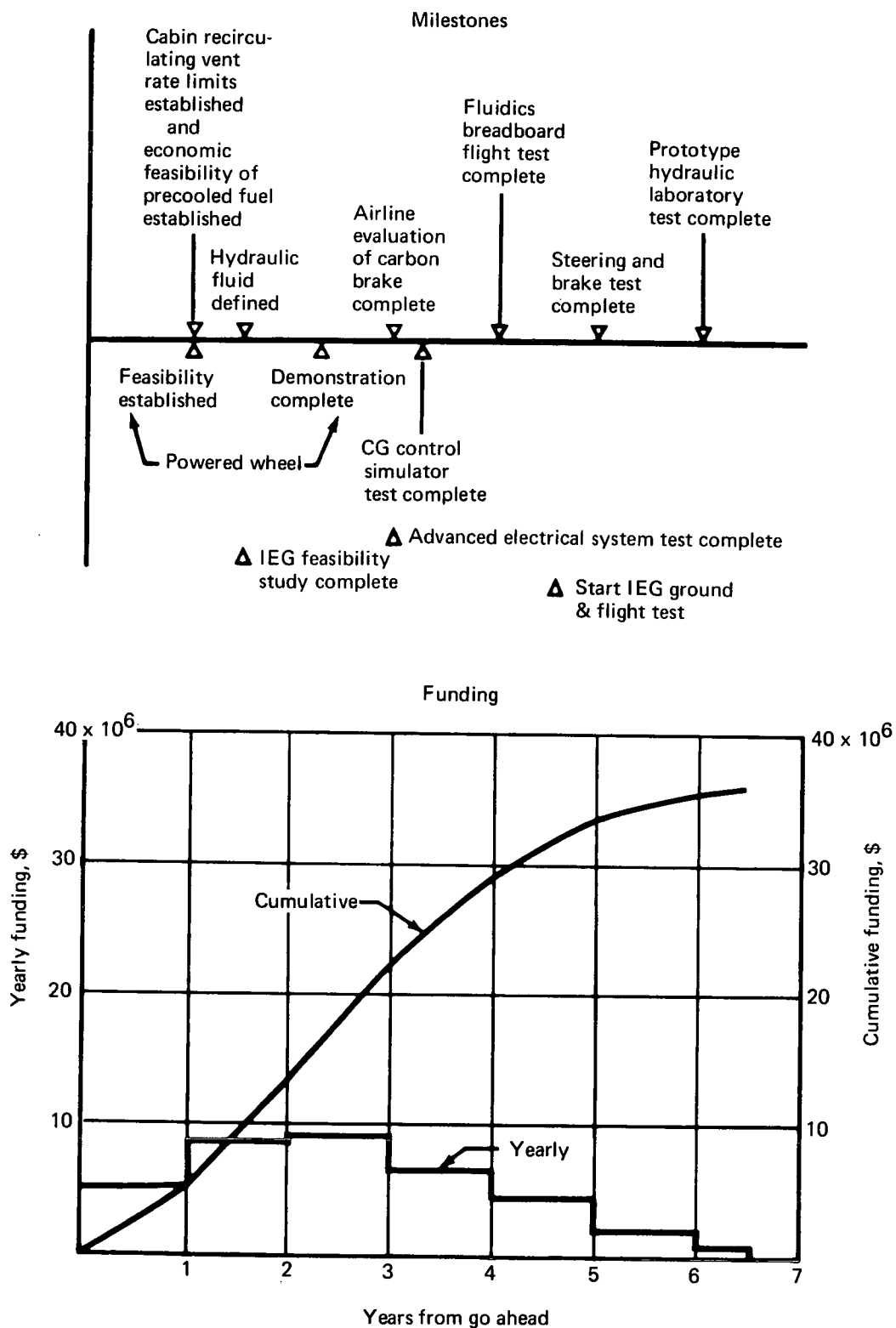


FIGURE 89.— AUXILIARY SYSTEMS SUMMARY

Category A items are technology advances which have been developed through the laboratory phase, and in some cases have been incorporated in military or experimental airplanes. Generally, performance benefits have been identified. Work is now required to achieve reliability and long life in an economical fashion consistent with commercial objectives. Specific items are:

- 4000 lb/in.² (2.76×10^7 N/m²) operating pressure.
- High speed pumps.
- Hydro-fluidic systems.
- Intermittent duty power sources.
- Fixed body actuators with flex rods for load attachment.

Category B items are new technology items which as of yet have not proven practical but indicate promise of performance and cost benefits. Such items include structure integrated fluid distribution, flywheel energy storage, and permanent assembly of hydraulic components.

Category C items are development activities resulting from technology trends in systems which interface with hydraulic systems. Work is required to adapt the hydraulic system to this new interface so that the full benefits of the technology advanced can be utilized. Proposed items are:

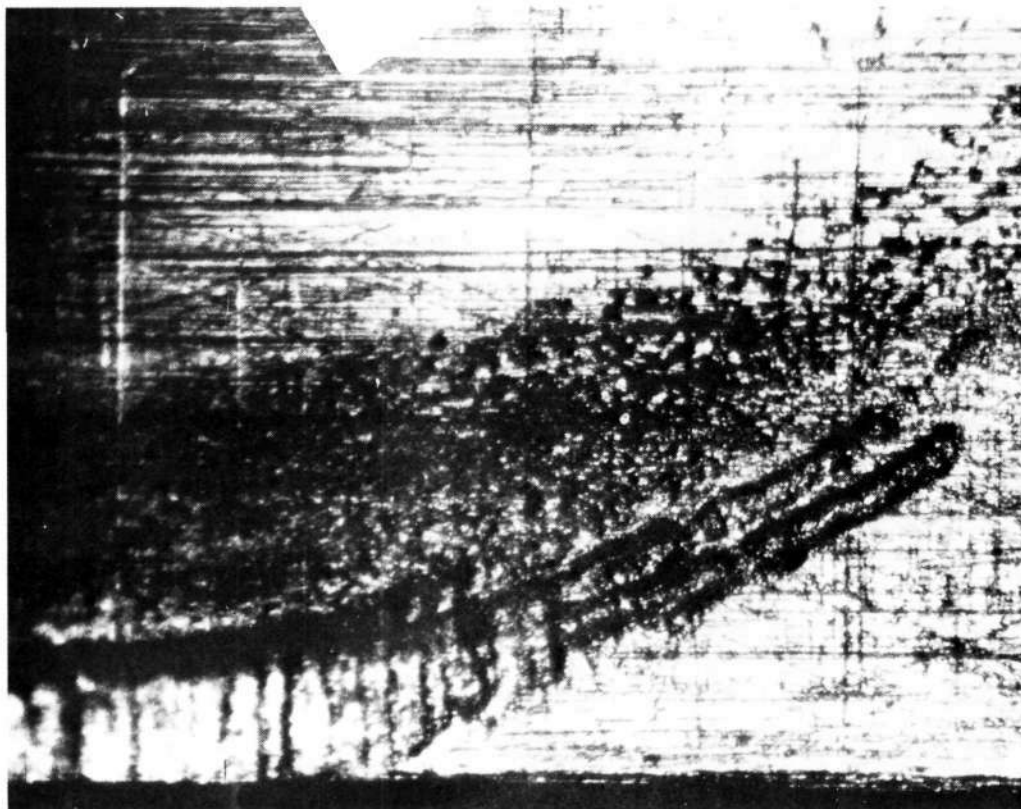
- Large integrated electric motor driven hydraulic pumps and power control units. The need for these items would be amplified with incorporation of an internal engine generator.
- Hydraulic motor driven generators of 5 to 10 kva size for standby power source.

Category D items are directed to solutions of problems inherent in present systems. Reduction of control valve erosion (see figure 90) and development of power transfer units fall into this class.

This development work is necessary to provide the most cost effective hydraulic system. The deficiencies to be improved upon are primarily excessive weight, initial cost, and maintenance cost.

Recommended Action.—Development effort is recommended in each of the above four areas. Priority should be given the valve erosion problem. NASA in conjunction with industry should prepare work statements leading to development program contracts. A proposed plan for these programs (analysis, hardware development, and test) is shown in figure 91.

Cost and Schedule.—The recommended research and development activities in the hydraulic systems area would require six calendar years for completion and an estimated total funding level of 12.8 million dollars.



*FIGURE 90.— EXAMPLE OF SEVERE CONTROL VALVE EROSION AFTER
100 HR OF LABORATORY TESTING*

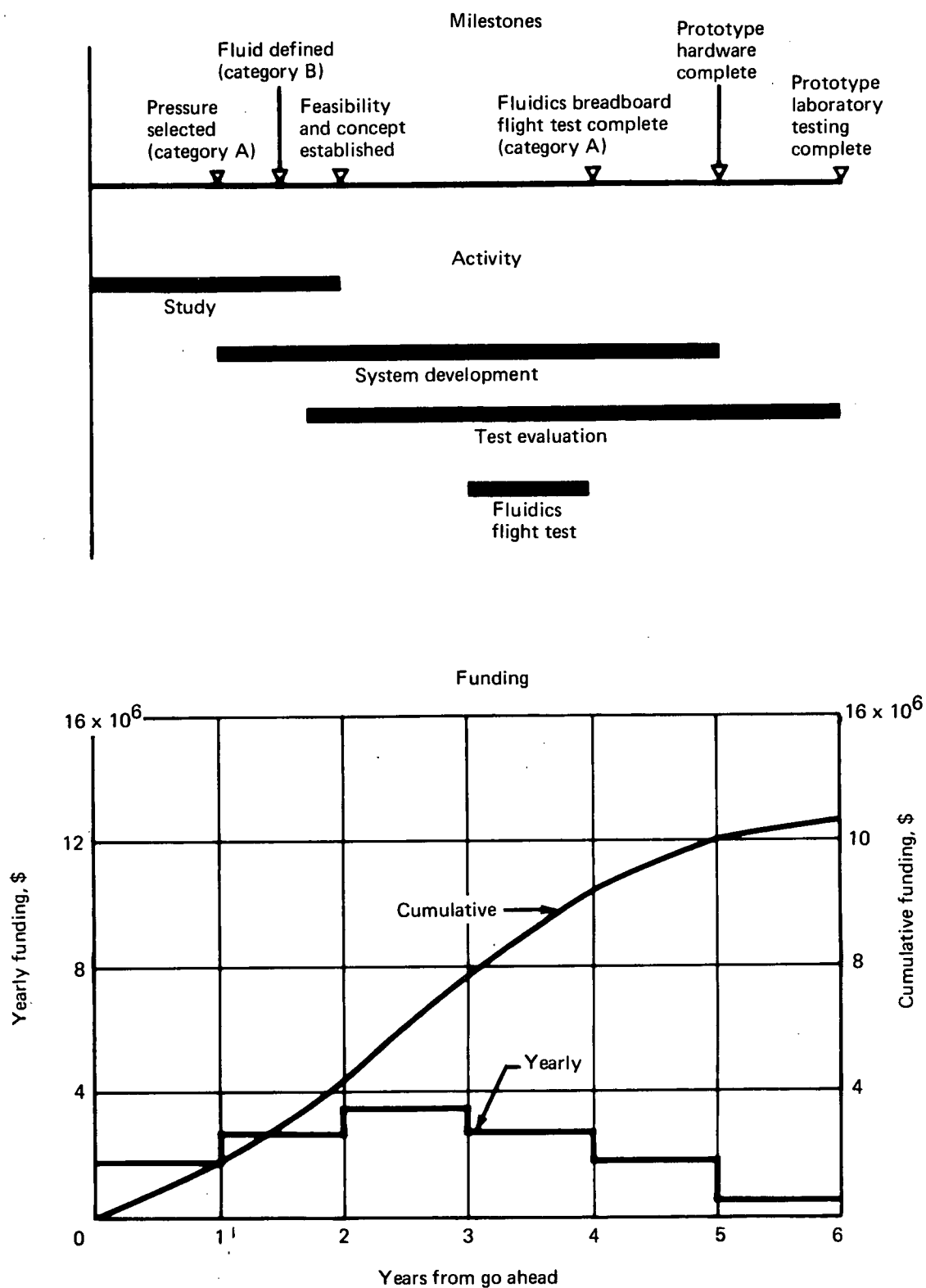


FIGURE 91.—HYDRAULIC POWER GENERATION, DISTRIBUTION, AND CONTROL PROGRAM PLAN

Advanced Electrical Systems

Potential Payoff.—The development and application of advanced design technique and hardware to the electrical system offers the following potential benefits per airplane:

Items	Delta Cost Dollars	Delta Equip. Weight	Other Benefits
Advanced Electrical Distribution System	+25/50 k	-150/300 lb (68/136 kg)	—Reduced Crew Workload —Automated System
Advanced Wiring Techniques	-150 k	-200/300 lb (91/136 kg)	—Reduced Maintenance —Flexibility for Changes
Fail-Operative Power System	-5/7 k	-100/150 lb (45/68 kg)	—Increased Safety —Improved Reliability
Starter-Drive/ Generator	Breakeven	-100/125 lb (45/57 kg)	—0.8% Reduction in Drag* —Air Starter Eliminated
Total	-132 k	-550/875 lb* (250/398 kg)	

*This benefit would result in a reduction of 1.1% TOGW.

State-of-Readiness.—The results of concept evaluation studies and initial hardware development programs provide high confidence that the projected payoffs could be realized. The Contractor and others in industry have laboratory tested advanced electrical distribution systems (AEDS) employing such concepts as automatic load management with programmable logic, signal multiplexing, single point data entry and display, and remote power controllers, figure 92. In addition, application studies for systems employing various combinations of these concepts have been made. Study results show feasibility and high payoff potential, but also indicate the need for significant improvements in requirements, system design including extent of utilization, and hardware prior to application.

The development and application of advanced wiring techniques should be a particularly fruitful area with respect to savings of weight, cost, and maintenance. Research programs involving small gage wire (SGW) harnesses (reinforced) and flat conductor cable (FCC) confirm feasibility in airplane applications with attendant benefits. These benefits would be maximized when used in a total wiring concept utilizing integration/distribution/interconnecting centers. The use of centers, with or without SGW or FCC, would allow the maximum use of standard point-to-point bundles requiring the minimum amount of coding. Wire integration within the center would provide maximum flexibility and capability to effect changes and repairs. Automation in interconnection programs would improve reliability. Initial application studies and limited hardware testing have been completed. A substantially expanded effort would be required to realize the full benefits of advanced wiring technology on future aircraft of the 1975-1985 time period.

The trend in aircraft design is toward greater use of electrically powered, fail-operative, flight-critical systems. A major effort would be required to match the electric power system configuration to user equipment requirements without incurring excessive penalties. A number of electrical power system concepts aimed at providing adequate safety and reliability

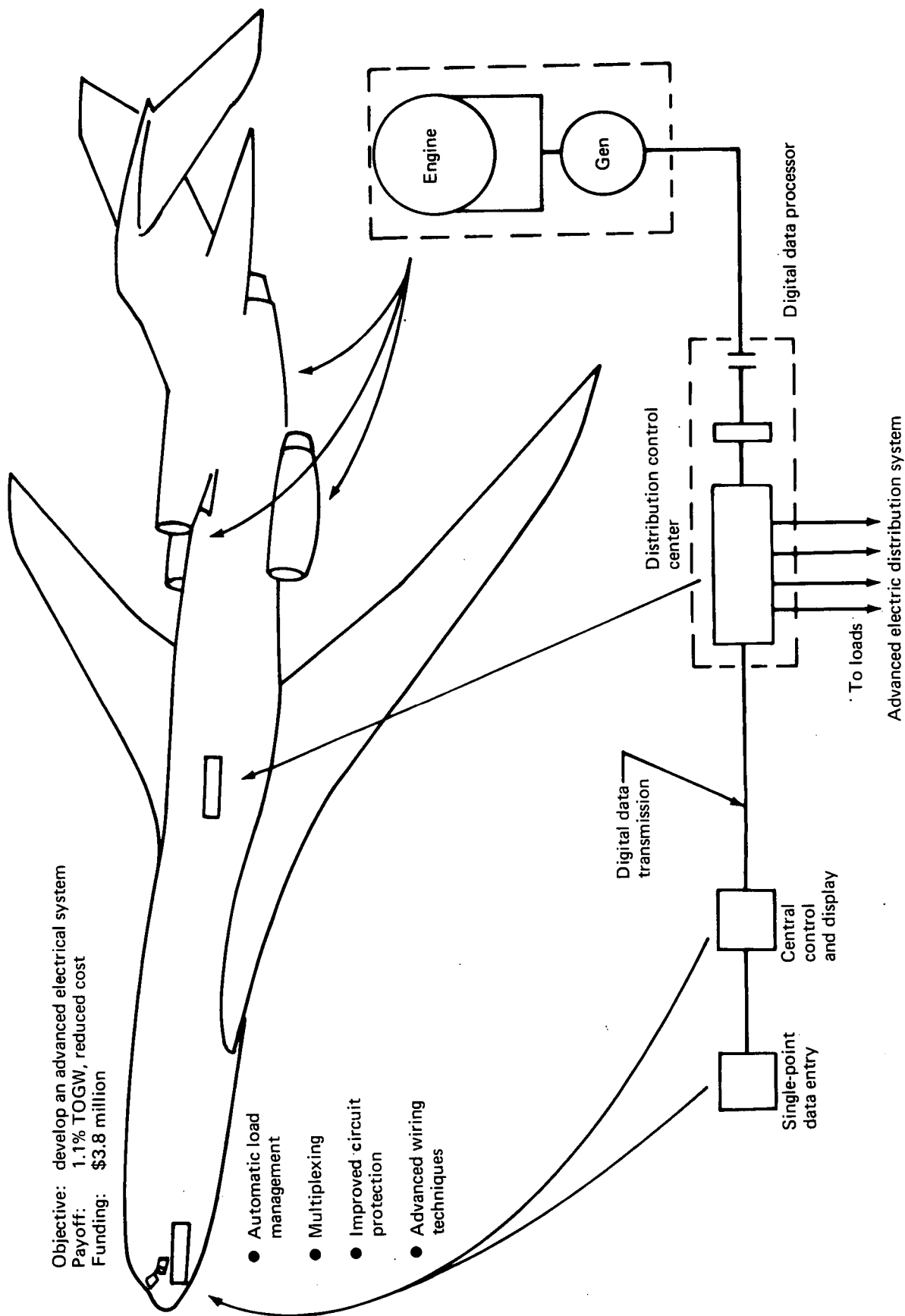


FIGURE 92.— AIRPLANE LAYOUT OF ADVANCED ELECTRICAL DISTRIBUTION SYSTEM

have evolved during recent Contractor research programs. Analysis of these concepts reveals the need for expanded effort to reduce the cost and weight of fail-operative power system configurations.

The development of a constant speed drive (CSD) and generator with engine starting capability would permit a significant reduction in engine frontal area and reduced system complexity. This approach was given serious consideration for the 727 airplane and considerable development progress occurred during the early 1960's. A recent re-evaluation of the starter-drive/generator concept indicates a highly reliable system could be developed. This concept could be an interim approach to the Internal Engine Generator discussed separately.

Recommended Actions.—A three phase program, figure 93, is proposed:

- Phase I—This effort would be primarily analytical and would conduct electrical system configuration evaluations; perform definitive trades of selected concepts; and identify development items for the subsequent phase.
- Phase II—Selected hardware would be designed, built and tested in the laboratory. Probable candidates are listed below:
 - Hybrid remote power controllers (1/2 to 75 amp ratings).
 - Advanced wiring techniques—small gage wiring harness, flat conductor cable, distribution/interconnection centers.
 - Fail-safe load transfer system.
 - Fail-safe APU intertie system.
 - Automatic electrical energy management system.
 - Integrated starter/drive-generator and controls.

A firm selection of equipment must await completion of Phase I.

- Phase III—Correct problems uncovered by the hardware test program. Prepare a design guide for applying new wiring techniques.

Cost and Schedule.—The recommended development program outlined herein would require 3.5 calendar years for completion and a total funding of 3.8 million dollars.

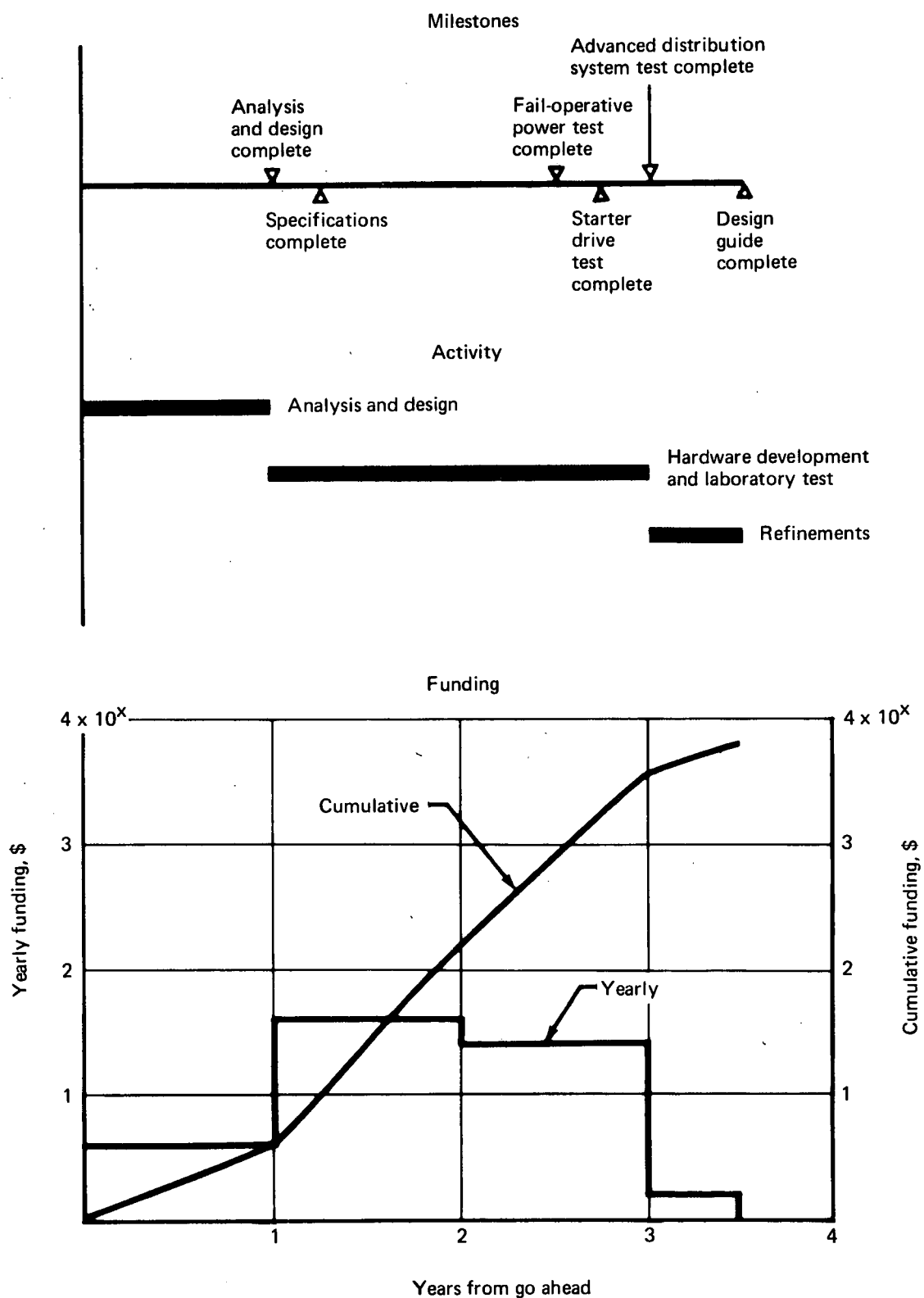


FIGURE 93.—ADVANCED ELECTRICAL SYSTEM PROGRAM PLAN

Internal Engine Generator

Potential Payoff.—The internal engine generator-starter (IEG) concept permits elimination or a reduction in size of the engine gear box or engine mounted accessories resulting in engine frontal area reduction. Expected payoff per airplane is as follows:

● Drag Reduction	1.2%	} 0.8% TOGW reduction
● Equipment Weight Change	+150/200 lb (68/91 kg)	
● Generator Reliability (50k-100k hours MTBF)	3:1 Improvement	
● Maintenance	Improved Accessibility (“Clean Engine”)	

State of Readiness.—Preliminary studies have been conducted to determine concept feasibility. Potential drag reduction, impact of equipment weight on the airplane, and the electrical capacity required of a generator/starter developed as an integral part of the propulsion engine has been evaluated. (See figure 94.) The Government and industry have been active in this preliminary work.

The need to reduce engine frontal area and attendant drag on the United States Supersonic Transport prompted a design which utilized a remotely located engine shaft driven accessory drive system mounted in the wing. A variable speed constant frequency (VSCF) system was developed for this application. The IEG concept involves mounting the generator rotor and stator as an integral part of the engine and employment of the VSCF concept to obtain constant frequency electrical power and to program voltage and frequency for engine starting. The studies indicate that the IEG could be mounted in the engine cavity without causing protrusion on the nacelle, providing it is integrated into the basic engine design.

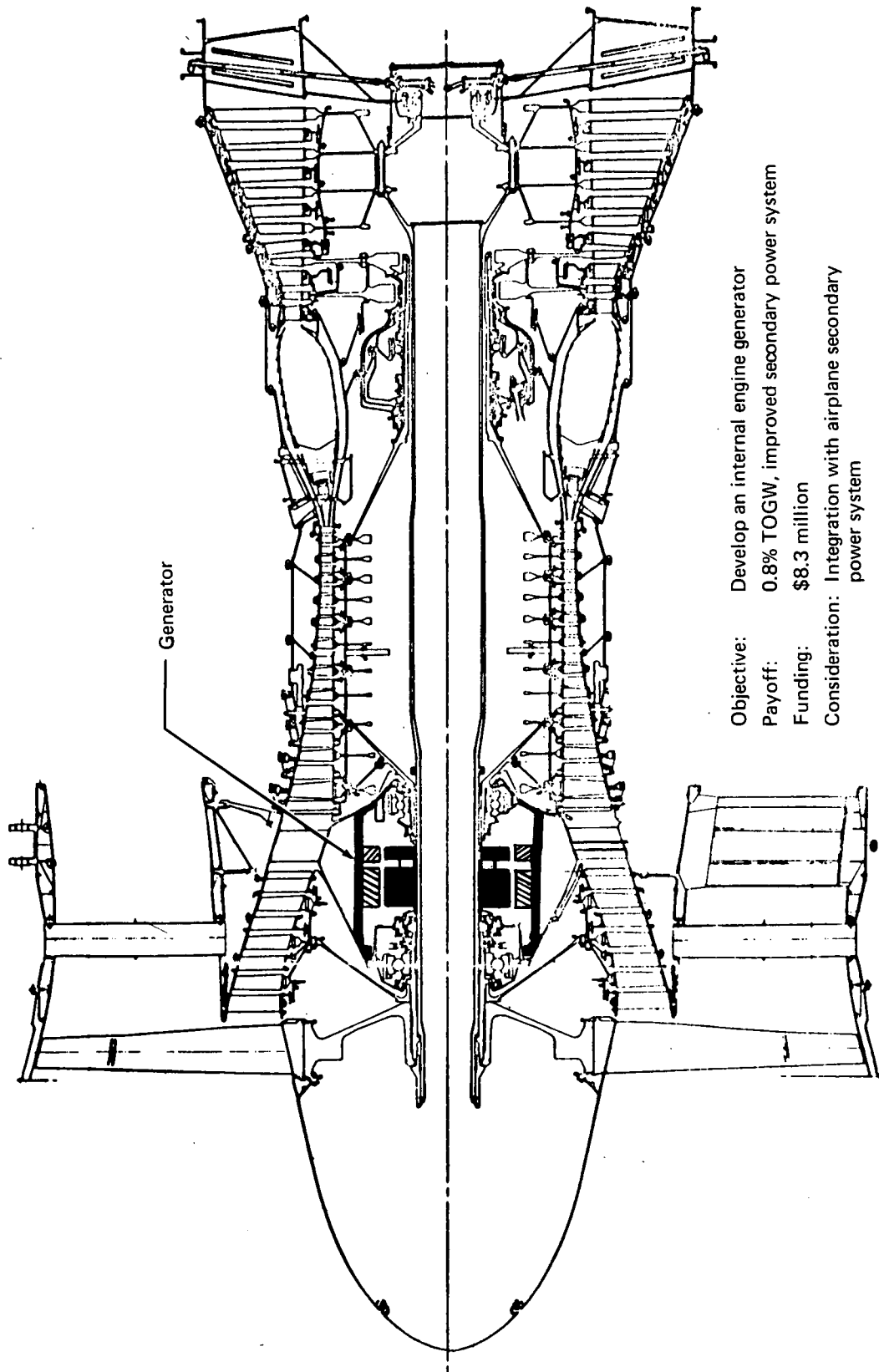
Reliability is a major consideration and a mean-time-between-failure of 50,000 to 100,000 hours should be achieved. Electrical and propulsion industry engineering representatives have expressed confidence in technical feasibility.

Recommended Action.—The IEG development should be defined and contracted for by NASA in three phases as depicted in figure 95. Phase I places particular emphasis on analysis and tests to select the most promising VSCF concept—cycloconverter, dc-link, or hybrid. Phase II emphasizes generator/engine interface requirements and system performance. Phase III completes the development phase of the IEG with a flight test of a complete system.

Cost and Schedule.—The development program outlined herein would require 6.5 calendar years and a total funding of 8.3 million dollars.

Landing Gear Systems

Potential Payoff.—Research and development activities in the landing gear systems area could provide significant operational benefits, figure 96. Increased safety would be the prime



Objective: Develop an internal engine generator
 Payoff: 0.8% TOGW, improved secondary power system
 Funding: \$8.3 million
 Consideration: Integration with airplane secondary power system

FIGURE 94.—INTERNAL ENGINE GENERATOR

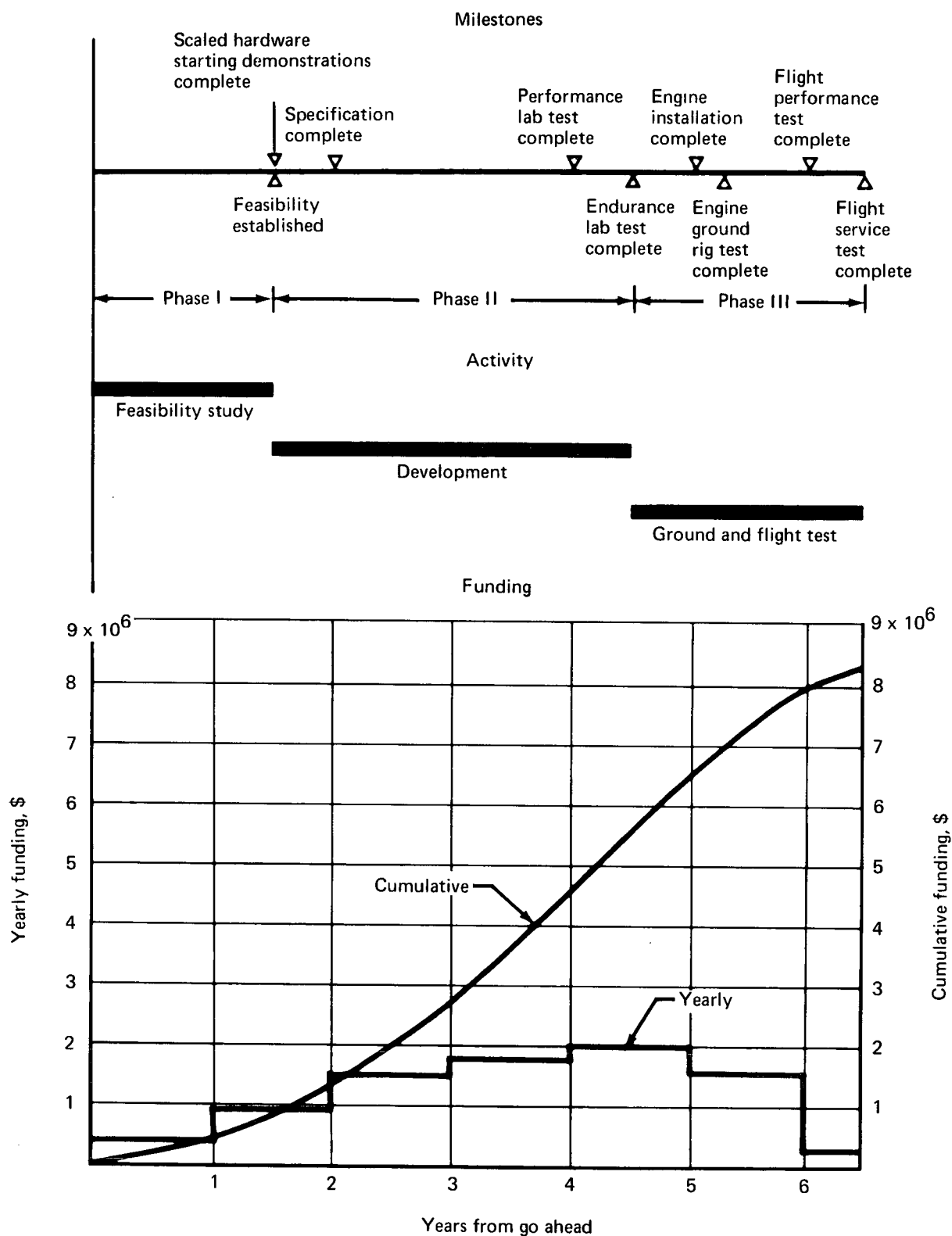
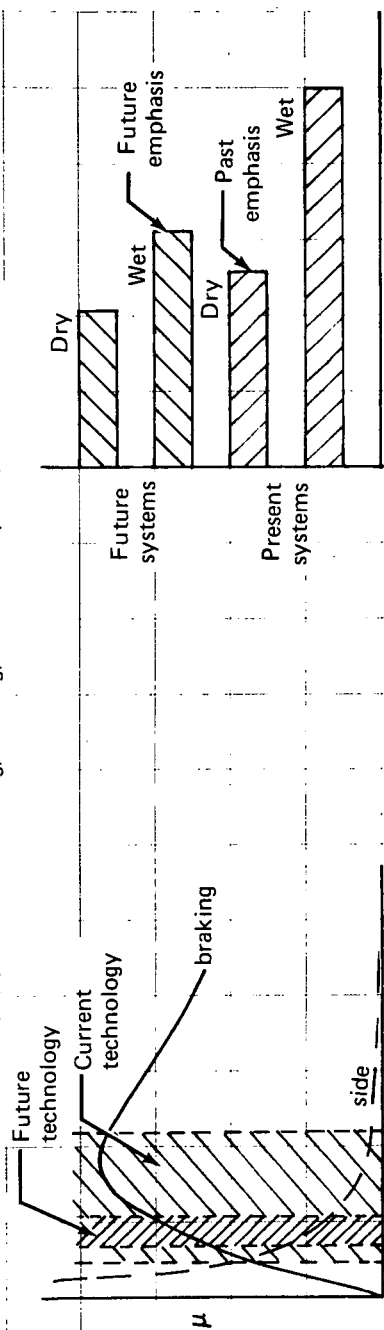


FIGURE 95.— INTERNAL ENGINE GENERATOR PROGRAM PLAN

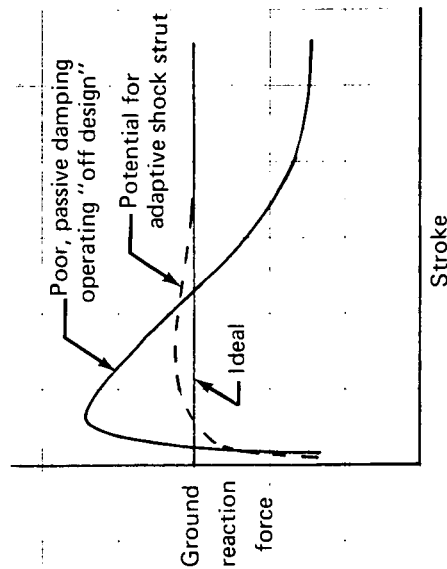
Objective: Develop advanced landing gear systems and criteria
 Payoff: Increased safety, reduced costs
 Funding: \$4.5 million
 Considerations: Braking, steering, shock absorption, and flotation



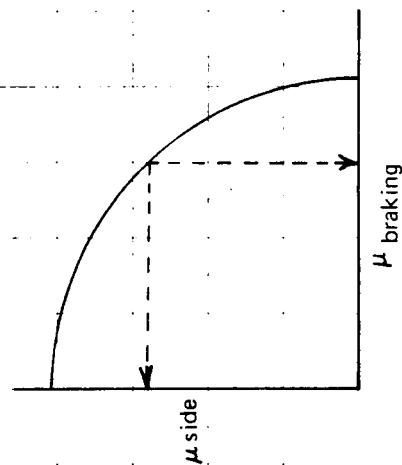
Stopping distance
 Field Length

Skid Control Characteristics

- Improved
- Ground handling
 - Stopping
 - Tire wear
 - Ride comfort



Shock Strut Characteristics



Tire Characteristics

FIGURE 96.— LANDING GEAR SYSTEM PERFORMANCE

benefit in terms of a reduction in overrun and veeroff incidents. Thirty overruns and forty veeroffs occurred in the U.S. in the 1967-1970 time period. Other performance improvements expected include a potential reduction in landing field length of 250 ft (76 m) and 1000 ft (305 m) for dry and wet runways, respectively.

Maintenance savings of \$100,000 or more per year per airplane should be realized. Program risks associated with current design approaches would be substantially reduced. Taxi ride and runway life would be additional benefits.

State-of-Readiness.—The current NASA-USAF-Industry tire program should provide an increased level of understanding of the characteristics of the tire and tire-runway interface. This information coupled with the application of adaptive feedback control system technology should yield improved brake and steering control systems for all-weather operation.

Prevention of brake squeal continues to be an art rather than a science. The contractor has developed a device to screen lining material for squeal sensitivity. Considerable future effort is essential to gain technical insight into the squeal phenomena so that the associated vibration problems can be prevented.

Available sophisticated structural analysis tools should be applied to airplane flotation analysis to develop a consistent, world-wide flotation criteria. Expected new regulations covering wet runway field lengths require development of an inexpensive ground vehicle for prediction of aircraft stopping distances.

Advances in fluidics technology make possible a development program for an adaptive shock strut system to improve “off design” performance and improve taxi ride.

Recommended Action.— It is recommended that NASA thru contracts with industry initiate a landing gear systems development program. A suggested overall plan, including analysis, hardware design and manufacture, and test is shown on figure 97.

It is anticipated that the first year effort would be primarily analytical. The most attention would be given to brake squeal elimination (highest priority) and adaptive shock strut concept evaluation. Analysis of brake control, steering, and flotation would be a relatively low effort.

The second years effort would be guided by results of previous work. Analysis would be expected to continue with emphasis on brake control and steering. Use would be made of results obtained from the NASA tire program and brake squeal work. Substantial squeal testing of brake material samples would be completed and design requirements to eliminate squeal defined. Flotation criteria analysis would continue. An adaptive shock strut system would be defined.

A third years effort would define prototype brake control and steering hardware requirements. An adaptive shock strut system would be built and tested and tests would be accomplished to establish runway flotation data.

Subsequent effort would include: design, manufacture and test of a brake control and steering system, establishment of universal runway flotation criteria, and flight demonstration of adaptive shock strut system.

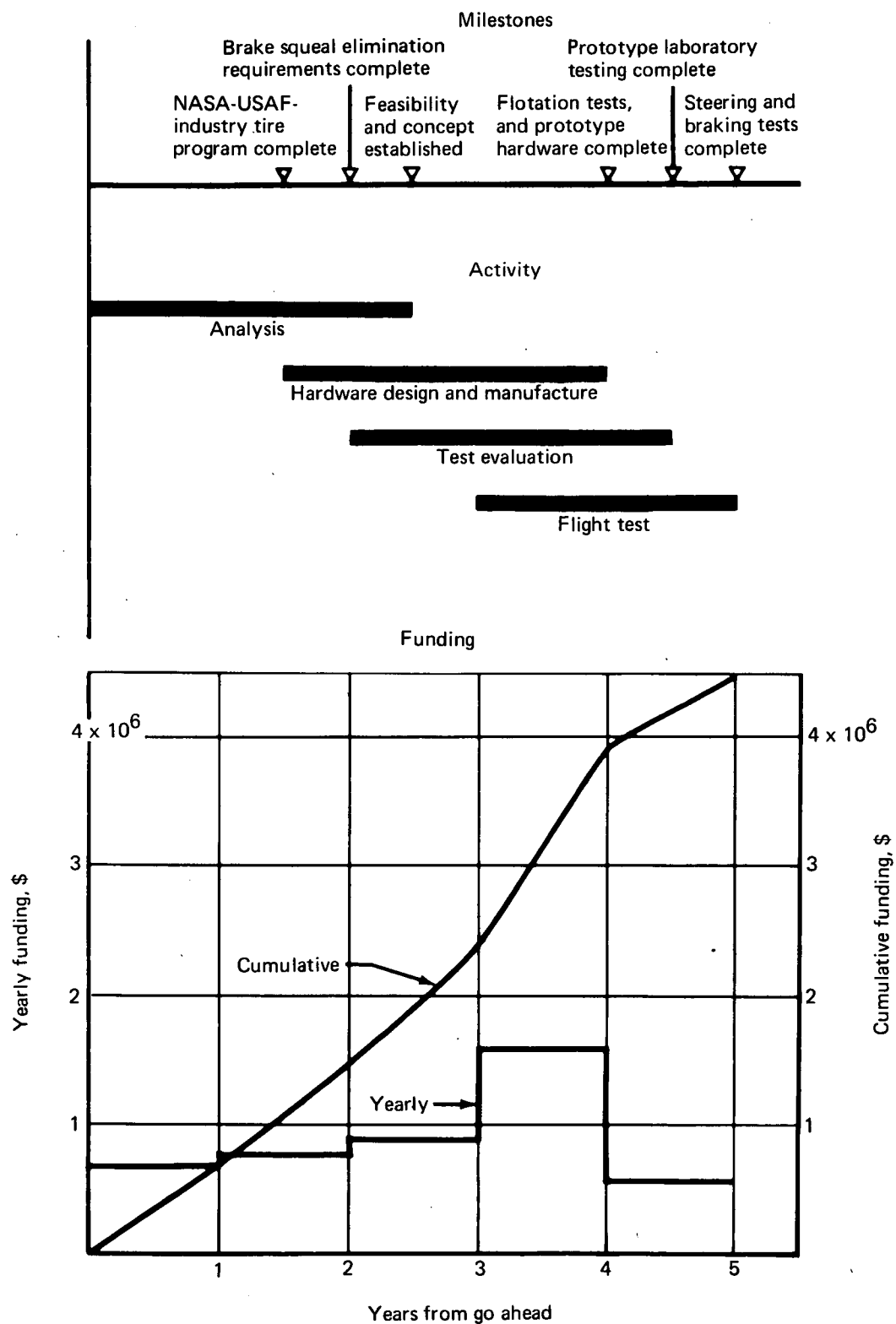


FIGURE 97.— LANDING GEAR SYSTEMS PROGRAM PLAN

Cost and Schedules.—The recommended landing gear systems developments would require five calendar years for completion and a total funding of 4.5 million dollars.

Structural Carbon Brake

Potential Payoff.—The use of structural carbon as both the heat sink material and friction lining material has considerable advantage as compared to present steel heat sink brakes, figure 98. The more favorable heat capacity per unit mass and the higher allowable operating temperature of structural carbon will allow a brake weight saving of up to 1280 lb (580 kg). This results in a 0.9% in TOGW.

The present material cost is approximately \$75/lb (167/kg), but with high production should drop by a factor of 10. Considerably longer life could be expected in airline use and lower maintenance cost should result from the less complex design.

The structural carbon brake should prove to be very cost effective and improve airline competitiveness in the world market.

State-of-Readiness.—Structural carbon brakes have been selected for both the B-1 and F-15 airplanes. Also the SST program had a carbon brake under development. Several brake suppliers are actively pursuing carbon brake developments. However, the noted activity is neither adequate or timely for commercial needs and an expanded effort is essential. Some 737 airplanes are fitted with low profile tires and thus would be readily adaptable as a test vehicle. Ample space would be available for the larger brake without increasing wheel size. This probably would not be true on other airplanes where wheel wells are usually congested.

Recommended Action.—A multi-phase program which leads to an early in-service evaluation of a carbon brake is recommended. The initial Phase would be a four month preliminary design and analysis effort to evaluate and screen various supplier brake materials for minimum squeal characteristics. A lining test facility would be required for sample testing. This effort would also assist in establishing design requirements.

Phase II would establish a brake procurement specification, initiate procurement, and accomplish hardware design, manufacture of laboratory test hardware and qualification tests.

Phase III would procure and install flight test hardware in a Model 737. Sufficient testing would be accomplished to permit certification for airline use.

Phase IV would procure and install hardware for one in-service 737 for airline evaluation. About 250 landings per month could be achieved which would permit evaluation of the brake through several overhaul cycles.

Cost and Schedule.—The 3-1/3 year program plan, shown on figure 99, is estimated to require a total funding of 1.5 million.

Powered Wheel System

Potential Payoff.—Development of a powered wheel system to provide ground maneuver capability without the use of main engines or two tugs has several benefits, figure 100. Ground pollution would be reduced 65 to 80 percent. Ground noise could be reduced up to 7 dB (aft) to 38 dB (forward) when measured on "A" scale at 200 ft (61 m) radius. Elimination of the

Objective: Develop a structural carbon brake

Payoff: 0.9% TOGW reduction

Funding: \$1.5 million

Considerations: Performance and service life

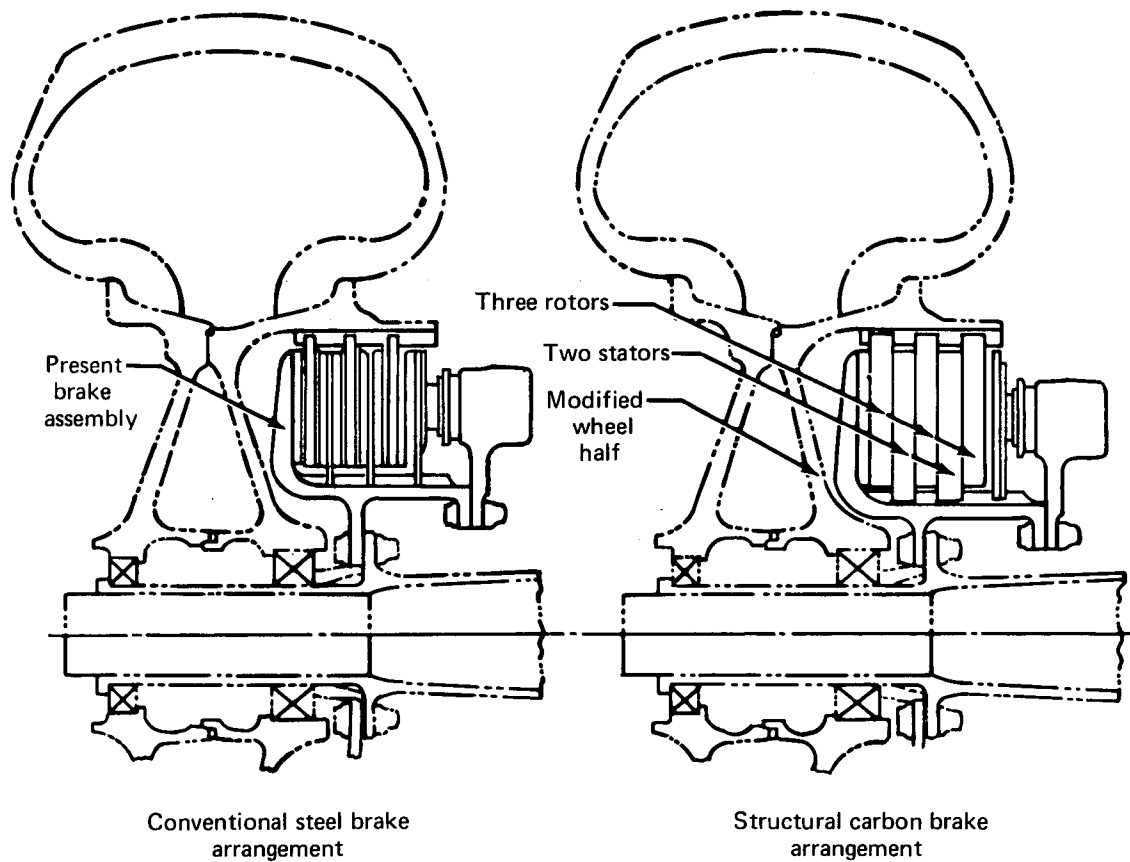


FIGURE 98.—IMPROVED BRAKE MATERIAL

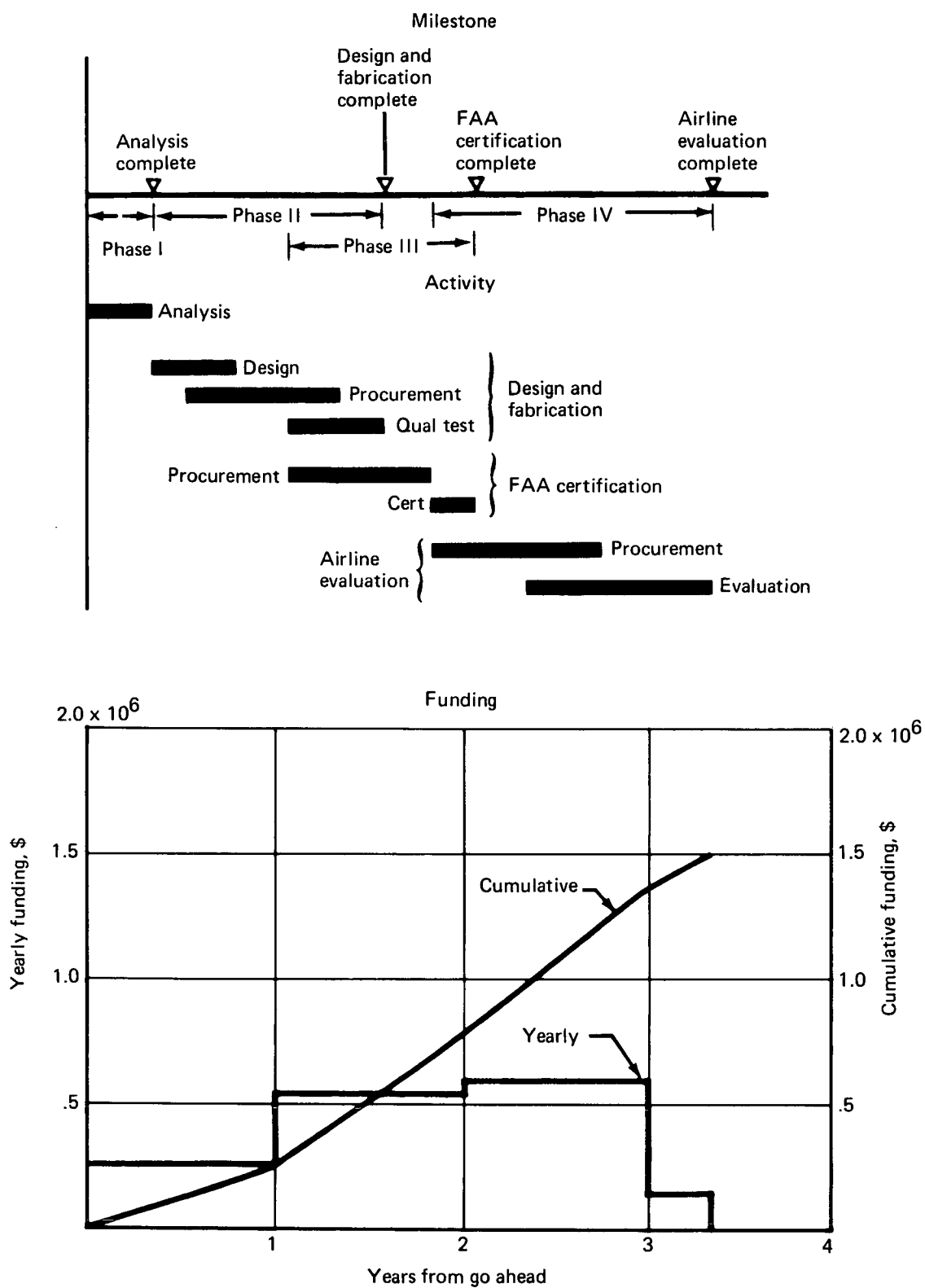


FIGURE 99.—STRUCTURAL CARBON BRAKE PROGRAM PLAN

Objective: Develop ground maneuver capability without use of engines or tugs
 Payoff: 65%-80% reduced ground pollution, 7 to 38-db reduced ground noise
 Funding: \$2.0 million
 Considerations: Power, traction, and breakaway friction

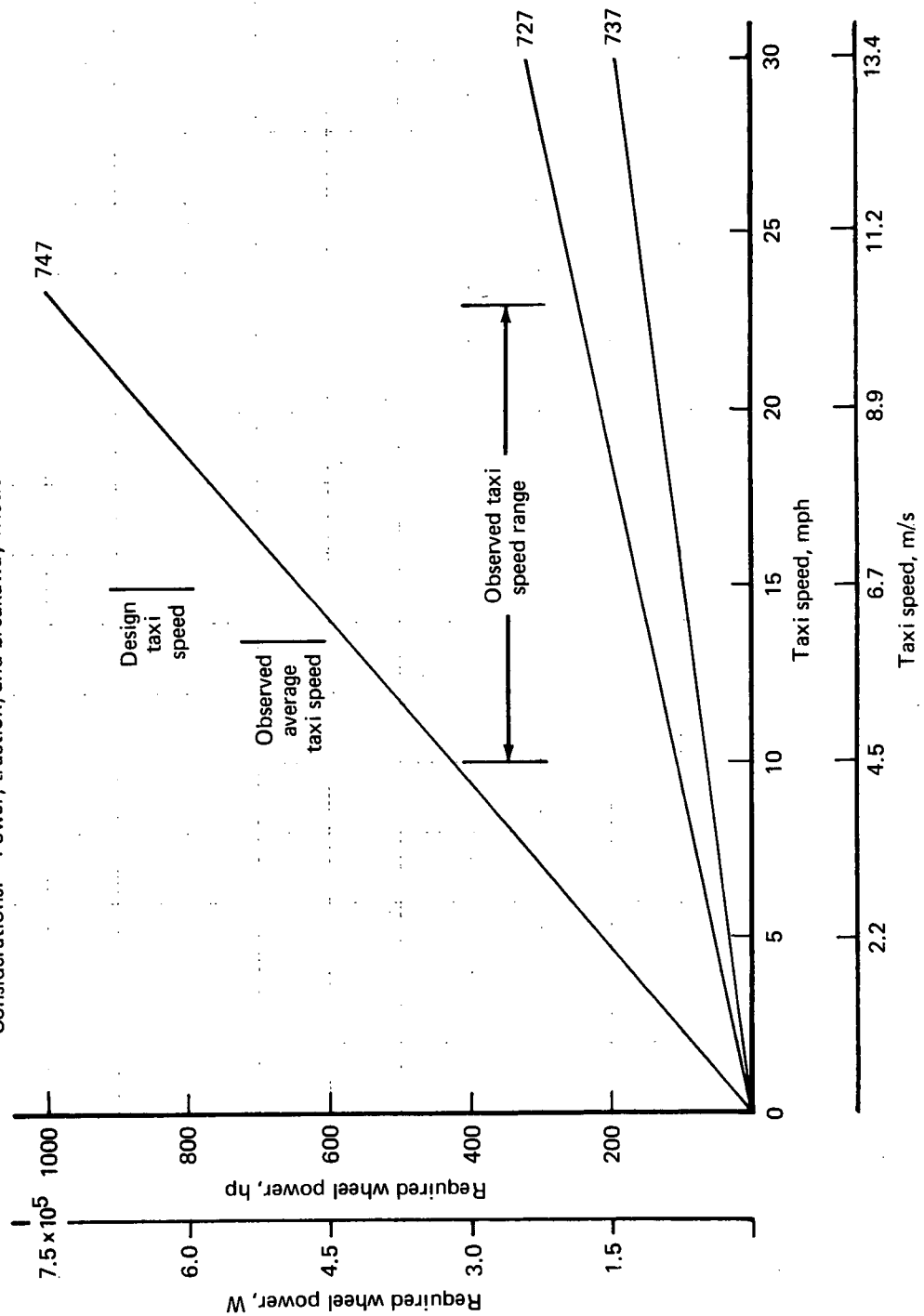


FIGURE 100.— WHEEL POWER REQUIREMENTS

jet wake in the terminal area would be a very positive safety benefit. Preliminary study shows that reductions in ground operation costs (reduced ground equipment and taxi fuel) in the order of \$30,000 per airplane per year could be expected to offset costs of a powered wheel system, however, some weight penalty would be expected.

State-of-Readiness.—The conceptual studies indicate the system is technically feasible. However, the practical application required study to determine specific methods and a more definitized understanding of the impact on airplane design and airline economics.

Recommended Action.—A three-phase approach is recommended with each succeeding phase dependent upon results of the completed phase. The first phase would be a one-year study. This study should include participation of two or three suppliers active in design of hydraulic, pneumatic, and electrical hardware and involvement of one or more airlines in determination of economic potential.

Phase I results would be a definite decision as to the practicality of powered landing gear wheels and a recommendation as to advisability of investigating other nonairborne ground maneuver systems.

If Phase I proves continuation of the powered wheel to be advisable, hardware development and demonstration would follow. The commercial jet transport, Model 737, is a practical vehicle for use as a demonstrator. The torque and horsepower requirements are reasonable, the landing gear is a relatively simple tricycle type, a suitable auxiliary power unit is available, and the airplane operating cost is low. All phases should be funded by the Government because there is little economic motivation for private industry funding.

Cost and Schedule.—The initial study phase is estimated to cost approximately \$200,000 over a one-year period. Total program estimated cost is 1.4 to 2.6 million dollars over a three-year period. The plan is shown on figure 101.

Pneumatic, Conditioning and Protective Systems

Potential Payoff.—Advanced technology improvements in the pneumatic, conditioning, and protective systems area have the potential of reducing system weight by 800 lb (364 kg), cruise drag by 300 lb (1340 n), and cruise specific fuel consumption by 1-3/4%. These items are equivalent to a cycled takeoff gross weight reduction of 2.8%. In addition, these improvements should reduce maintenance cost and airline warranty claims.

State-of-Readiness.—Contractor research, engineering work for the United States Supersonic Transport, and industry effort in design of the 747/DC-10/L-1011 airplane systems have exposed and identified development items having the potential of achieving the above gains. Specific items are: expansion of cabin air recirculation, air source development, fuel auto-geneous ignition temperature definition, precooled fuel conditioning, cooling cycle evaluation, deicing system (cordwise parting strips concept), low drag cooling system design, windshield heating system, and total energy management/secondary power concept development.

Some current subsonic jets utilize a limited amount of unfiltered cabin air recirculation. The SST program investigated use of precooled fuel and sponsored preliminary development

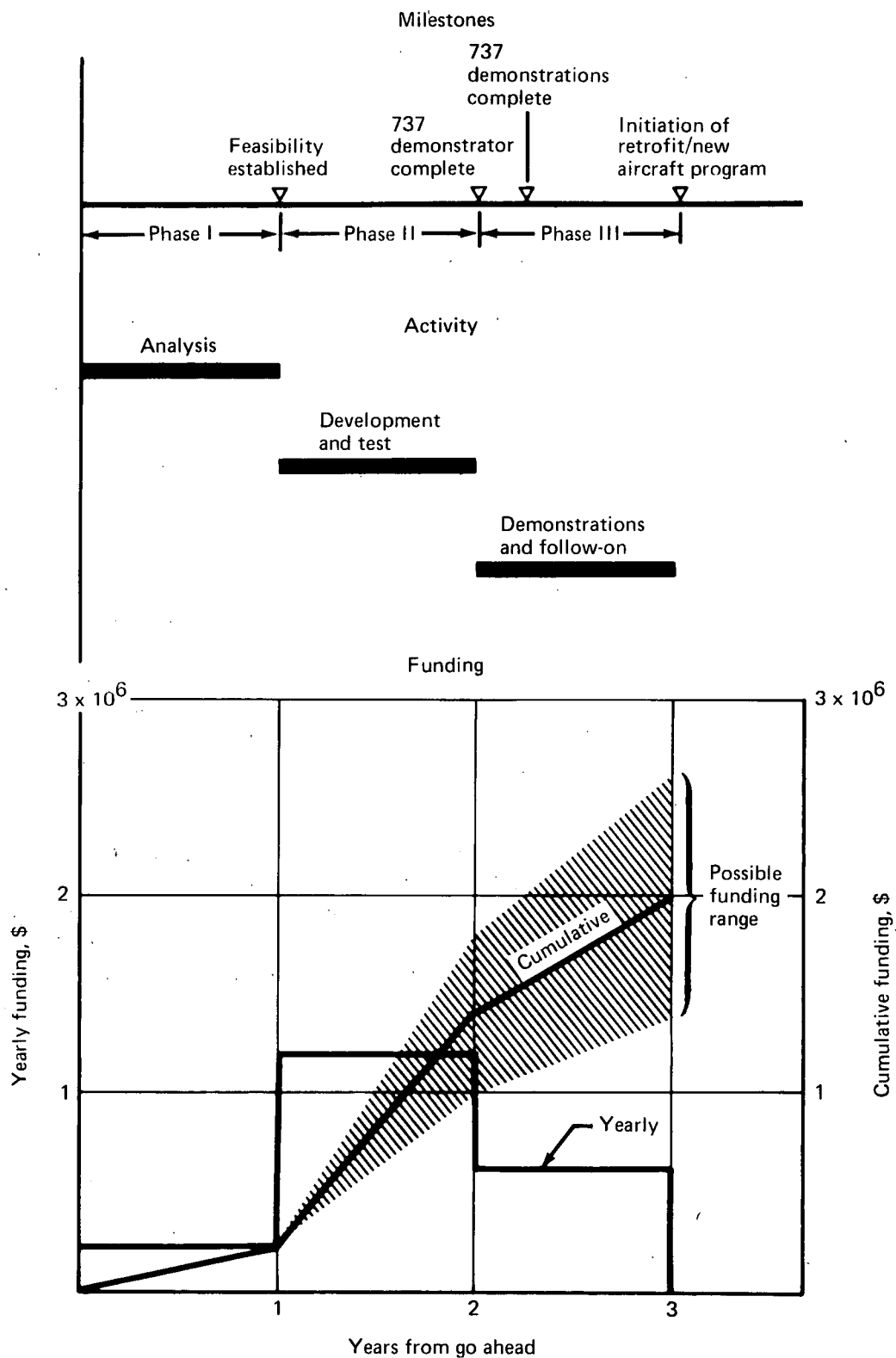


FIGURE 101.— POWERED WHEEL SYSTEM PROGRAM PLAN

of shaft driven boost compressors. Substantial data is available on fuel autogeneous ignition temperature in general but data on the fuel vapor/air duct interrelationship is lacking. Several approaches to overall systems energy management have been pursued by industry without a positive solution.

Recommended Action.—It is recommended that a program be initiated and funded by NASA as follows:

- Phase I—Initiate analysis of the items that would most likely impact requirements of the engine (long lead item). These items would be cabin air recirculation, fuel autogeneous ignition temperature, precooled fuel and cooling cycle evaluations. Results should include: Evaluation of existing data, establishment of design criteria, identification and analysis of promising concepts, and identification of hardware for test. Priority should be given to the cabin air recirculation study, figure 102.
- Phase II—Continue elements of work initiated in Phase I and determined worthy of additional effort. Tests should be completed and recommendations for systems changes specified. A definitive plan for Phase III should be provided.
- Phase III—Initiate analysis design and test work on items not included in Phase I and not critical to engine development but significant to airplane development.

Cost and Schedule.—A Program Plan is shown on figure 103. Phase I would encompass the first year and Phase II the following year. Phase III is currently estimated to require a three year effort. The predicted total program cost is 1.2 million dollars.

Fuel System Improvement

Potential Payoff.—The objectives of the program are: 1) to develop a technically feasible center of gravity control system enabling improved aircraft performance; 2) to systematically develop criteria for gelled fuel performance in a commercial transport airplane fuel system together with definition of the required fuel specifications; and 3) to refine analytical techniques to include definition of hazard levels in fuel tanks in terms of fuel properties and internal geometry. The payoff from work in these areas would be improvements in aircraft performance and safety.

State-of-Readiness.—

- C.G. Control—Currently existing computerized analyses can determine quantity of fuel and location of its C.G. from basic airplane geometry, airplane attitude and level of fuel above a datum. They also can compute gaging error due to the location and nature of the sensing probes. Advanced fuel gaging systems with increased accuracy and dependability are in the development stage. Prototype control systems need to be designed and tested.

Objective : Define an optimum air recirculation system
to improve overall airplane efficiency
Payoff: Equivalent to 1% TOGW reduction
Funding: \$185,000

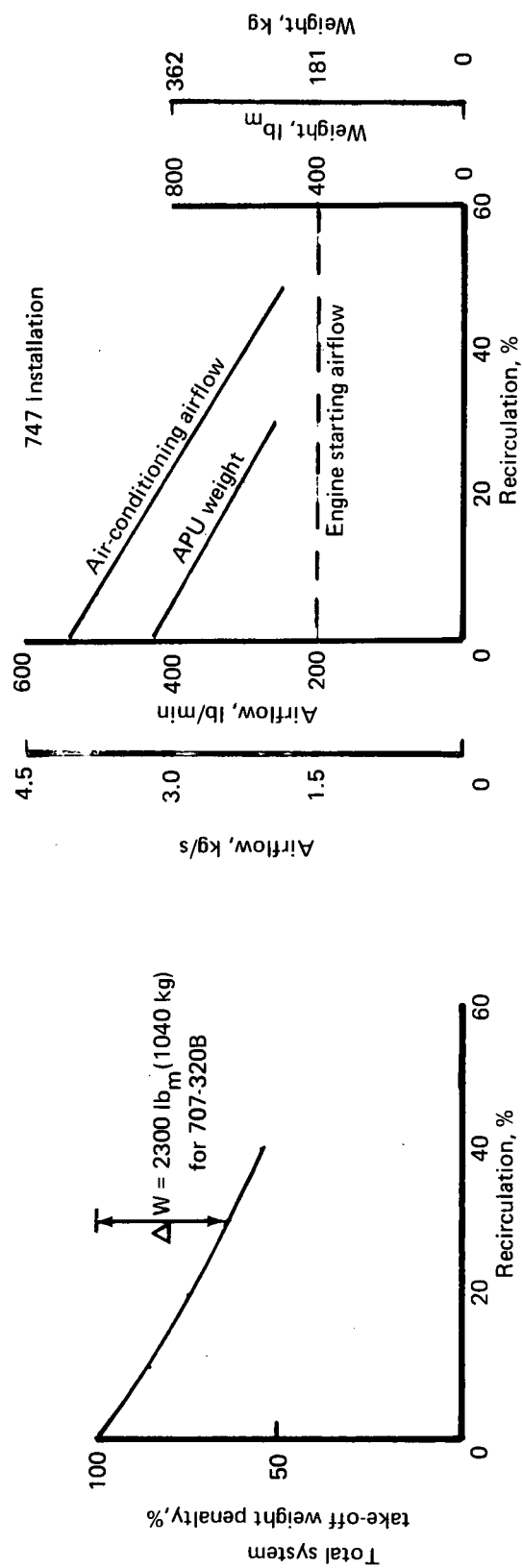


FIGURE 102.—CABIN AIR RECIRCULATION DEVELOPMENT

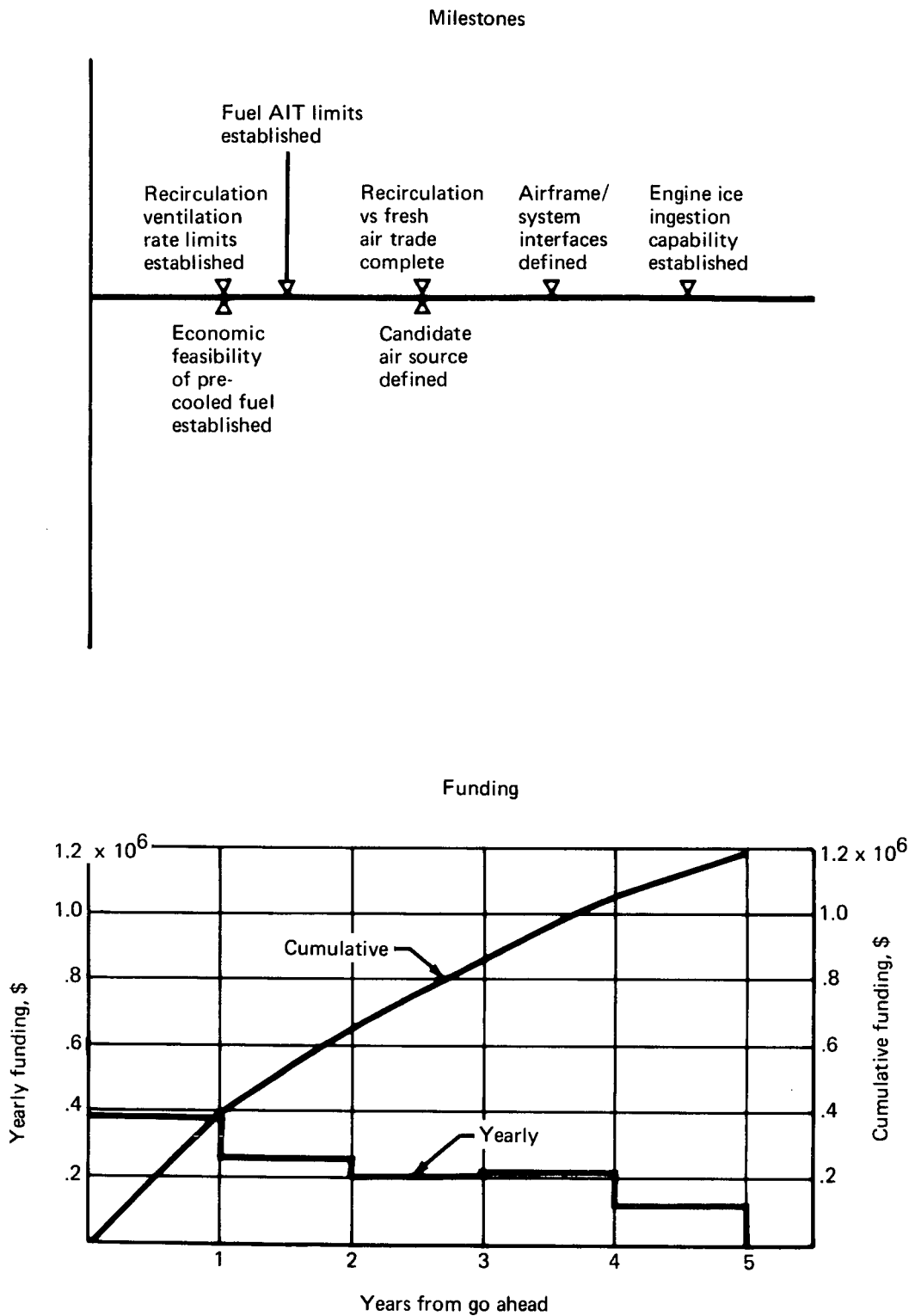


FIGURE 103.— PNEUMATIC, CONDITIONING, AND PROTECTIVE SYSTEMS PROGRAM PLAN

- Gelled Fuels—Some gel formulations now available and being further improved show promise of being compatible with airplane fuel systems and providing a margin of safety in survivable crashes. However, since limited test data are available for measuring gel usefulness and since its performance in fuel systems cannot presently be predicted, criteria for system design are needed.
- Electrostatic Fuel Charging—Analytical solutions for field strength, surface potential, surface charge density and surface energy density exist. The solution is in computer form, output being both tabular and plotted. These programs can accept variations in tank size and proportions and in incoming fuel charge density and fill rate. This analytical technique has been used successfully to design airplane fuel systems which do not depart markedly from previous, safe designs. However, there is no method for determining absolute safe limits, or to predict safety margins for new airplanes with dissimilar tank construction.

Recommended Action—

- C.G. Control—Design, optimize and analyze performance of a system, using an onboard computer with preprogrammed information so that fuel gage system output can be converted to accurate c.g. location. Design an independent fuel shifting system controlled by the computer and integrated with the airplane fuel system. Utilize latest techniques to improve gaging accuracy and reliability. Develop hardware and electronic devices; assemble and test a breadboard arrangement. Build and test a full scale simulated tank, gaging and pumping system.
- Gelled Fuels—Tests will be developed to measure system performance and safety advantages. Determine system limitations and revisions necessary for use of gelled fuel. Qualify best available gel in a modified fuel system and engine, and for compatibility with system materials and environment. Perform ground and flight tests using modified FAA flying test bed.
- Electrostatic Fuel Charging—Revise the existing computer program to treat more conditions. Verify analytical predictions and experimentally effects of unconventional full tank design and actual refuel practice. Modify an existing fuel flow facility for test purposes and construct test hardware to provide a survey of geometry, size, arrangement and internal projections. Determine by test and spark energy associated with certain regular shaped electrodes as a function of field strength, electrode gap and surface energy density.

Cost and Schedule.—A program plan is shown on figure 104.

- C.G. Control—Six months to complete design and analysis, one year to develop hardware and two years to complete testing. Three and one-half years total, \$980,000.
- Gelled Fuels—One and a half years to complete analysis and qualification tests. One year for preparing test airplane and conducting flight tests. Two and one-half years, \$630,000. Cost does not include alterations, use, and flight of the FAA 990 airplane.
- Electrostatic Fuel Charging—One year program. \$200,000.

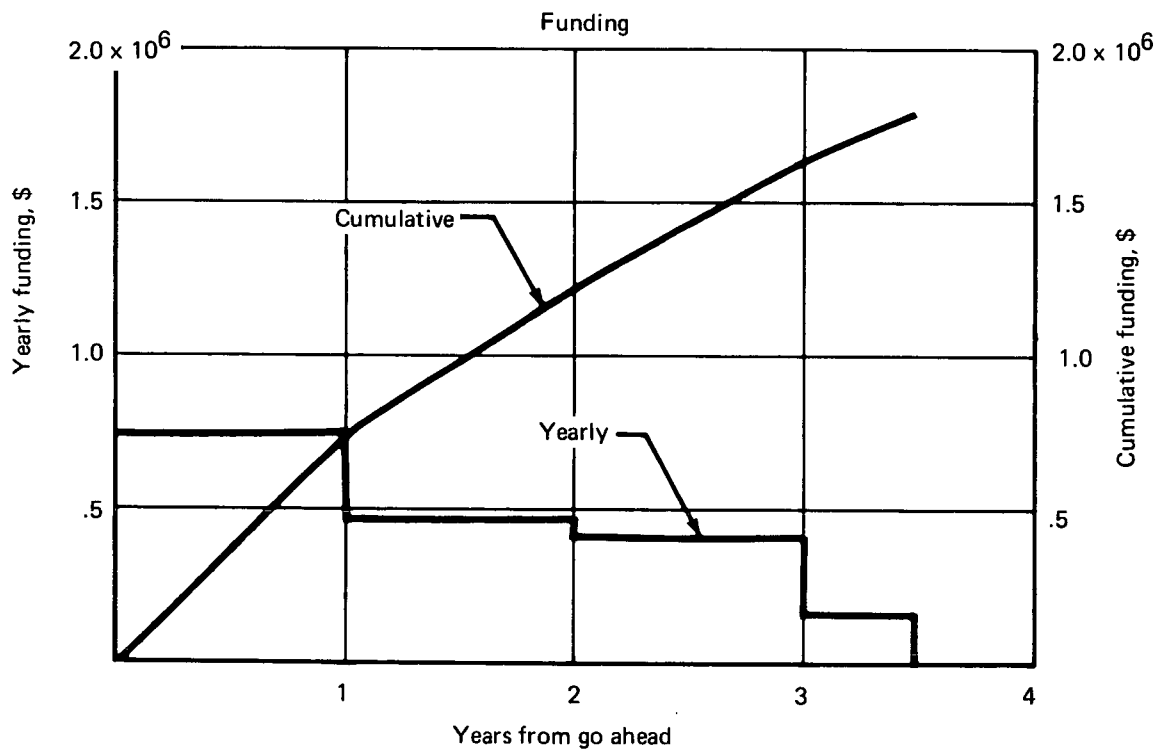
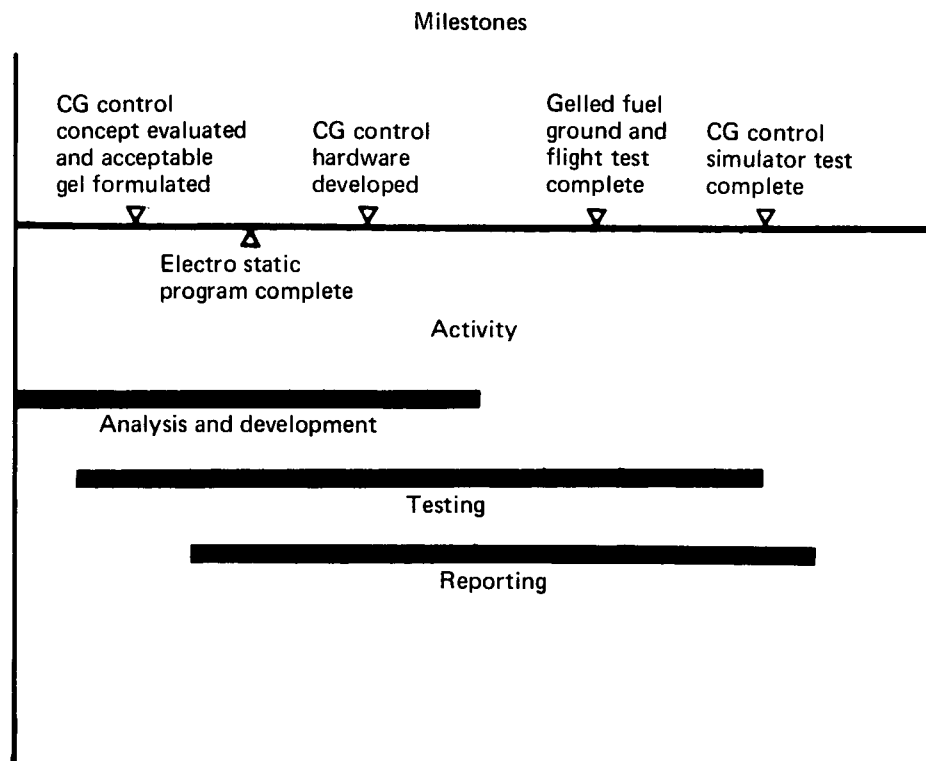


FIGURE 104.—FUEL SYSTEM PROGRAM PLAN

CONTROL OF FLIGHT

The study reported in Volume I of this document, identified the operational procedures and flight control system additions that are necessary to achieve community noise reductions, contribute to the solution of airport congestion, and improve vehicle performance. In order to realize these benefits, additional research and development is necessary in the Control of Flight area. The suggested research involves Flight Control technology in predominantly an analysis role: determining limitations, improving analysis methods, and developing new control concepts. The Avionics items are predominantly those leading to systems definition.

The recommendations include an estimated cost and schedule in order to specify the level of effort suggested for each item. Control of Flight recommendations require the expenditure of approximately \$19 million over a six-year period. The recommendations have been grouped into three categories: Flight Controls, Avionics, and ATC/Operations as shown in figure 105. A breakdown of recommended funding levels is shown in figure 106.

The work in the Flight Control area, requiring the expenditure of approximately \$1 million over a two and one-half year time period should be undertaken by either the NASA or an airplane manufacturer familiar with the design of long-haul vehicles, as identified on each

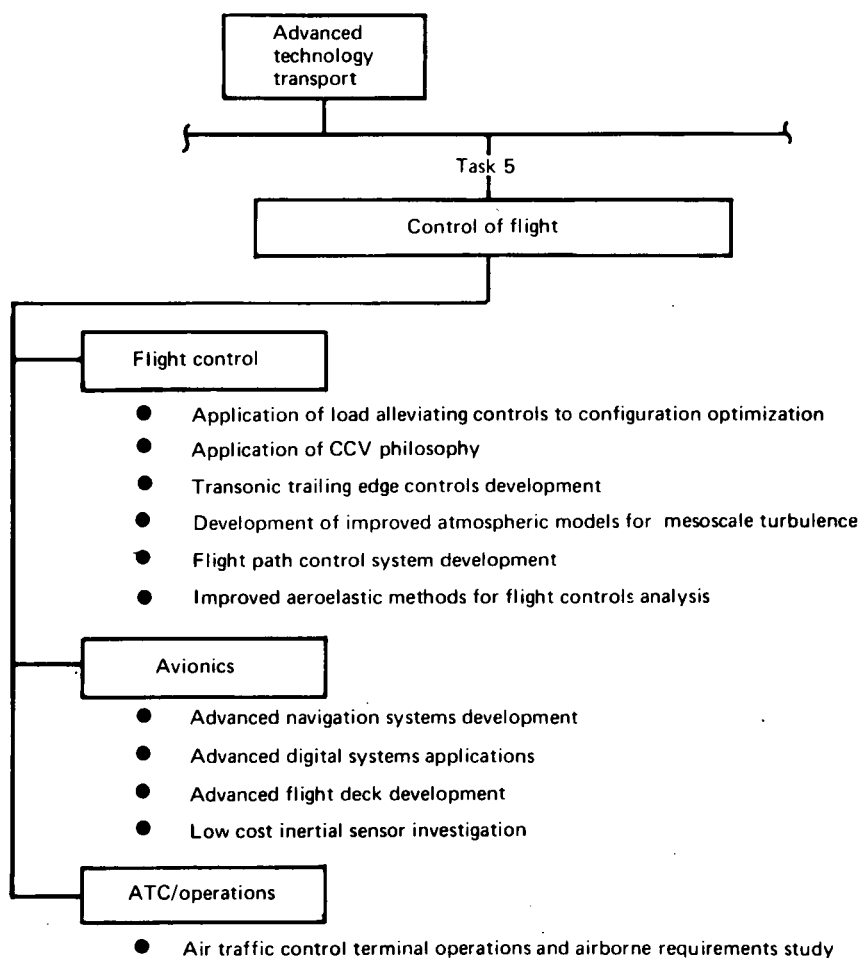


FIGURE 105.—RECOMMENDED RESEARCH ITEMS

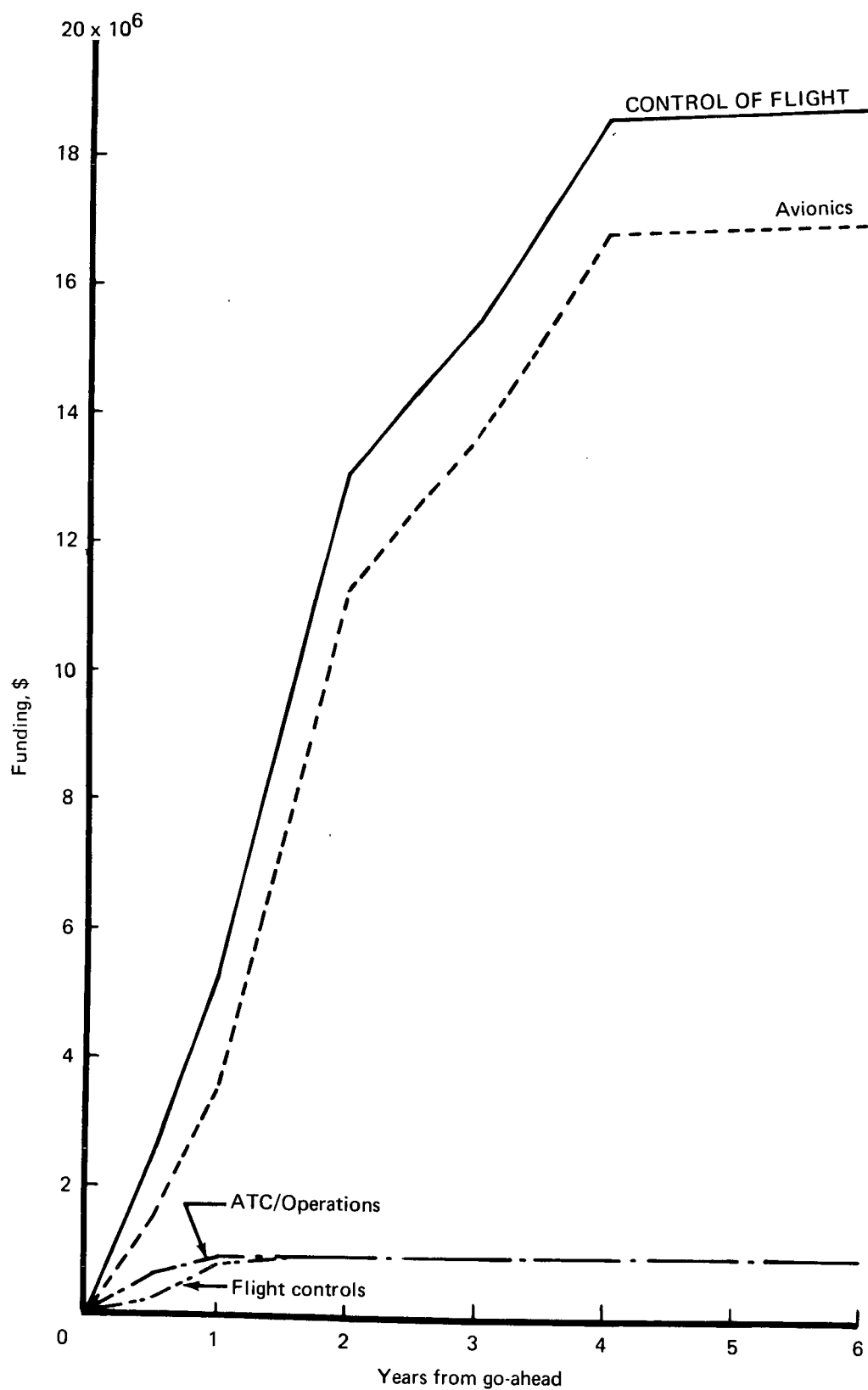


FIGURE 106.— RECOMMENDED CONTROL OF FLIGHT RESEARCH FUNDING

item. The work in Avionics (\$17 million over six years) and ATC/Operations (\$1 million over one year) should be accomplished by industry under NASA programs.

Application of Load Alleviating Control to Configuration Optimization

The successful application of load alleviating control systems in configuration design requires the development of suitable control surfaces, their inclusion in the configuration, and the testing of the control system on a development rig. This approach requires the participation of flight control technology. However, rather than discuss the individual tasks separately, the total recommended program is presented in the active controls portion of the Structures and Materials section.

Application of CCV Philosophy

Potential Payoff

Traditional airplane design philosophy relies on airplane balance and empennage sizing to provide inherent stability. Typically the resulting airplane is longitudinally stable throughout the flight envelope, with moderately unstable Dutch roll at the high speed, high altitude corner of the envelope. Stability augmentation can then be added to the design to provide improved characteristics for normal operation. However, the airplane is safe without the augmentation over most of the flight envelope.

Airplanes designed in this fashion exhibit suboptimum performance at cruise, and may be noisier than necessary at low speed. A design philosophy that strives to optimize the performance, at the expense of inherent stability if necessary, has been described as a Control Configured Vehicle (CCV) design philosophy. The application of this approach to a three-engine-aft Mach 0.98 ATT configuration that was designed to be independent of stability augmentation yielded an 11.5 percent reduction in takeoff gross weight. The design mission for both configurations was 3000 nmi (5,560 km) range with a 40,000-lb (18,144 kg) payload. An additional benefit should be quieter operation near the terminal since the more aft cg locations reduce the trim requirements.

State-of-Readiness

The application of the CCV philosophy to the longitudinal balance of an ATT configuration results in an airplane with an aperiodic divergence over a significant part of the flight envelope. This demands flight safety critical augmentation systems with the associated reliability, checkout and monitoring emphasis. The level of instability that can be successfully stabilized is dependent to some degree on the structural properties of the airframe, and significantly dependent upon the characteristics of the sensing, computational and servo elements of the flight control system. Prior to a design effort that includes the CCV philosophy from the outset, the limitations imposed by the considerations listed above must be determined. The effort necessary to identify these limitations is recommended in the following paragraphs. The suggested program does not include the subsequent design and testing of the control system since that naturally would be part of a new airplane design effort.

Recommended Action

The NASA should either undertake this study in-house, or initiate an industry contract with a suitably experienced airframe manufacturer. The system impact on the CCV application to an ATT configuration should be determined by developing the required augmentation for increasing levels of instability. These defined systems should then be examined in order to identify any limitations introduced in either analog or digital mechanization. The study should:

- Select a representative ATT configuration whose characteristics have been determined.
- Select a number of center-of-gravity locations extending aft to the limit of safe nose down control.
- Develop an augmentation control law that meets the design criteria for each center-of-gravity location.
- Examine the characteristics of an analog and digital mechanization for each of the conditions.
- Identify the limits of successful stabilization recognizing real sensor/computational/servo characteristics, the airframe structural properties, and the redundancy requirements.

Cost and Schedule

The expenditure of \$250,000 over a one-year period as shown on figure 107 is estimated as necessary to achieve the goals of the work statement. This would provide the necessary manpower and associated computational support for the duration of the study.

Transonic Trailing Edge Controls Development

Potential Payoff

Configurations designed to cruise at near-sonic speeds require controls with minimum weight and drag impact in order to achieve their desired performance. The plain flap type control offers good sensitivity and aerodynamically efficient forces or moments. However, the supercritical airfoil technology, which is a necessary element of transonic cruise, yields relatively thick airfoils. These thick airfoils operating supercritically would probably separate with modest deflections of a plain flap type control surface.

The application of circulation control concepts may provide a method of developing flap type controls with satisfactory effectiveness in the transonic speed regime. Through a program of theoretical and experimental development, the transonic characteristics of trailing edge flap type controls with circulation control on supercritical airfoils can be determined for use in the design of ailerons, elevators, and rudders on ATT configurations.

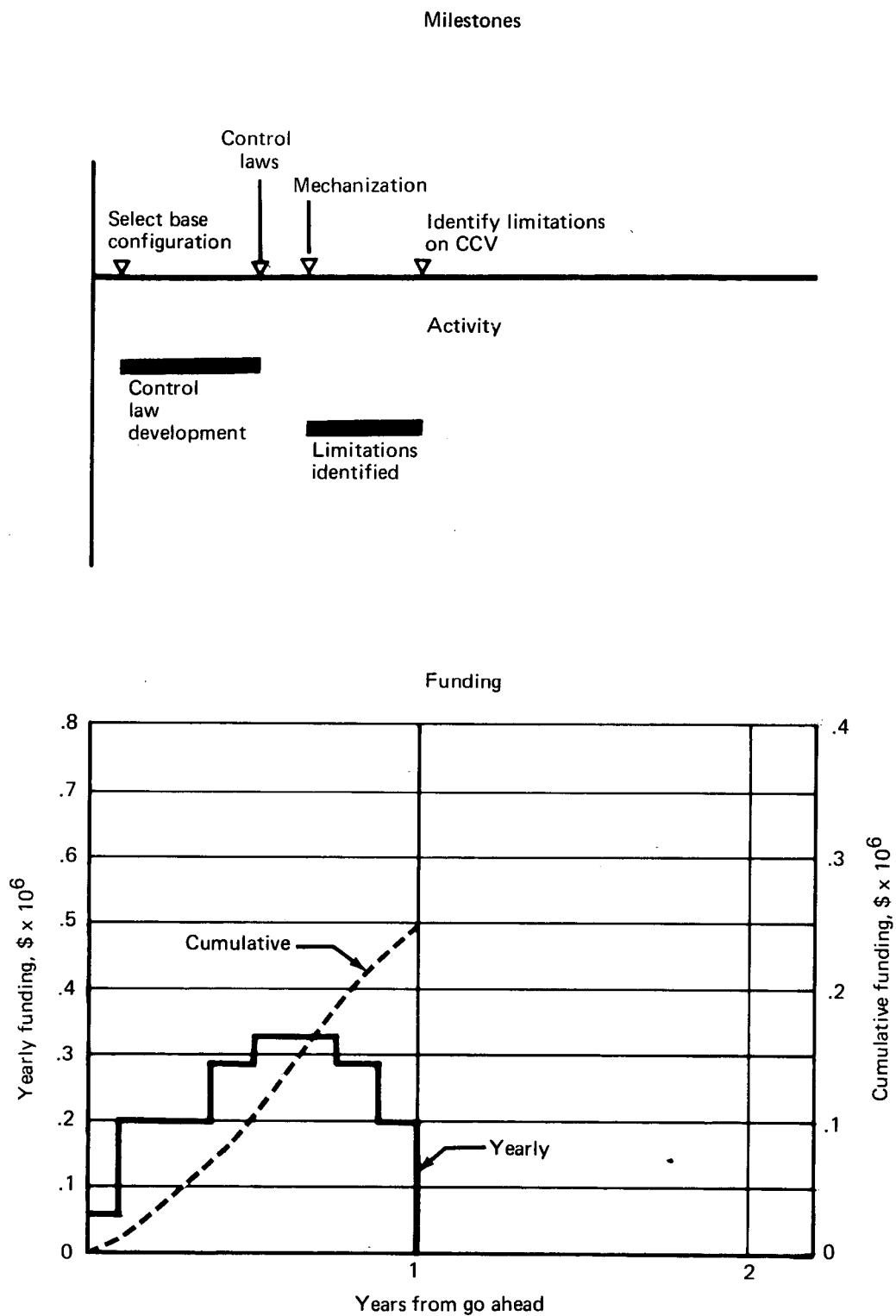


FIGURE 107.—APPLICATION OF CCV PHILOSOPHY—COST AND SCHEDULE

State-of-Readiness

The theoretical and computational elements required for design of these controls are currently available. The elements including treatment of boundary layer growth should be brought together into a single computational package for more efficient application to this problem. The theoretical development would necessarily be verified experimentally. Successful model construction and testing, in both two- and three-dimensions, can be accomplished with state-of-the-art techniques in existing facilities.

Recommended Action

The development of transonic trailing edge controls should be undertaken by the NASA or contracted for with industry or a university that has access to the necessary wind tunnel and model fabrication facilities and should:

- Design a circulation control for a typical supercritical airfoil section with a plain flap-type trailing edge control.
- Wind tunnel test 2-D sections with plain flap trailing edge with and without circulation control.
- Design an elevator and aileron, compatible with the available air supply, for a typical ATT configuration.
- Wind tunnel test a complete configuration to assess the transonic effectiveness.
- Design a system for an ATT configuration in order to assess the power requirements, weight, and cost.

Cost and Schedules

The recommended goals are estimated to be achievable with the expenditure of approximately \$250,000 over a period of 15 months as shown in figure 108. This includes engineering, programming, and the associated computer time. Also included is the design, fabrication and test of two-dimensional and three-dimensional models. Finally the analysis and documentation are estimated to require approximately three months following the completion of the three-dimensional test.

Development of Improved Atmospheric Models for Mesoscale Turbulence

Potential Payoff

Much of the benefit associated with advanced technology stems from eliminating unnecessary conservatism in the airplane design. This can be accomplished through an approach that places emphasis on the flight control system for flight safety. For instance, the use of integrated active controls to allow a reduction in the design loads, the elimination of inherent stability as a design feature, and the suppression of flutter in order to reduce the

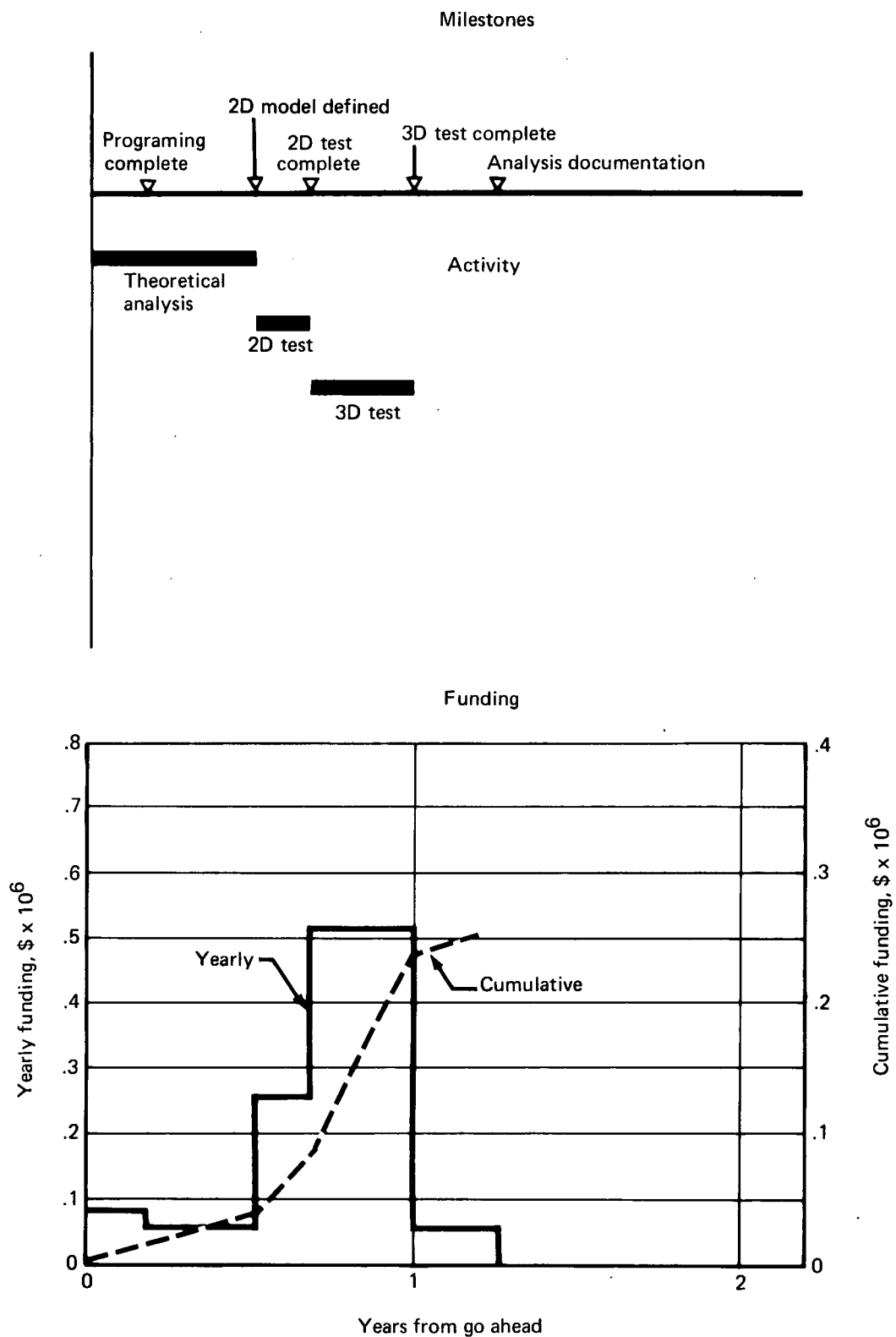


FIGURE 108.—TRANSONIC TRAILING EDGE CONTROLS—COST AND SCHEDULE

structural material, require the assumption of either greater risk or greater confidence in the analyses. Greater risk is not acceptable since it is desirable to enhance the safety of future designs rather than accept a degradation, so increased confidence is required.

Determining the response of these new airplane designs to gusts and turbulence involves a great deal of uncertainty. This uncertainty is primarily associated with the gust and turbulence models. The SST design studies identified atmospheric turbulence as the critical design factor for the flight control system, establishing control surface rate and hydraulic pump size for the landing configuration. The payoff of this development item would be improved confidence in the analysis and resulting designs.

State-of-Readiness

Since the introduction of jet transports into commercial service there have been a number of upsets and incidents stemming from atmospheric disturbances. Although the data records are limited in scope and quality, the airplane characteristics are well understood and these data are available for correlation. The necessary analytic tools are available for application to this task.

Recommended Action

This development should be undertaken or contracted for by the NASA. The model development should involve two phases, the first to gather flight record data and airplane characteristics definition for those upsets and incidents involving jet transports. These airplanes operate over flight envelopes similar to those proposed for ATT configurations. Limited to these airplanes, the study can remain unclassified.

The second phase would involve deducing atmospheric characteristics where possible, and correlating the proposed model with the recorded incidents. The study should include the following:

- Review the commercial jet transport upsets and incidents involving atmospheric disturbances.
- Assemble the characteristics of the airplanes involved in the above.
- Review the models in use in industry in the several specialties, (flight controls, structures, etc.) with those from certificatory agencies.
- Develop a mesoscale turbulence model that best fits the recorded events.
- Document the correlation with the initial data base.
- Identify the models recommended for use in design and compare to those currently used.
- Evaluate the turbulence model impact on the flight control system design for a typical ATT configuration.

Cost and Schedule

The goals of the work statement can be accomplished with the expenditure of approximately \$100,000 as shown on figure 109 to provide the necessary engineering and computing resources.

Flight Path Control System Development

Potential Payoff

The near terminal operational environment, circa 1980, will make severe demands on the flight control system of all operating airplanes. These demands will spring from the precision required by the traffic control and from the more demanding flight path management required for reduced community impact. Analysis of the terminal area implications on the flight path control system is necessary to provide the precision and flexibility that will be required of new airplanes without any deterioration in the level of safety. This analysis will lead to the identification and development of the required control system.

State-of-Readiness

The analysis of the flight path management task in the terminal area can be accomplished with existing computational and simulation facilities. Basing the study on designs for which the aerodynamic, propulsion, and mass characteristics are defined will allow an immediate start.

Recommended Action

A systems approach to the analysis of flight path management in the terminal area should be undertaken by an airplane manufacturer experienced in large transports, under NASA sponsorship, to identify the control system characteristics that best provide the required accuracy. Consideration must be given to noise abatement approaches with the associated problems of propulsion system response and control, transition altitude where the rate of sink is adjusted to the touchdown level, cockpit display properties, decrab, and go-around capability.

The study should:

- Specify the assumed terminal area environment.
- Select representative new study configurations whose characteristics have been determined.
- Analyse the terminal area flight path control task through a systems approach, to determine the optimum control characteristics and loop closures.
- Verify the control system performance with a piloted simulation.

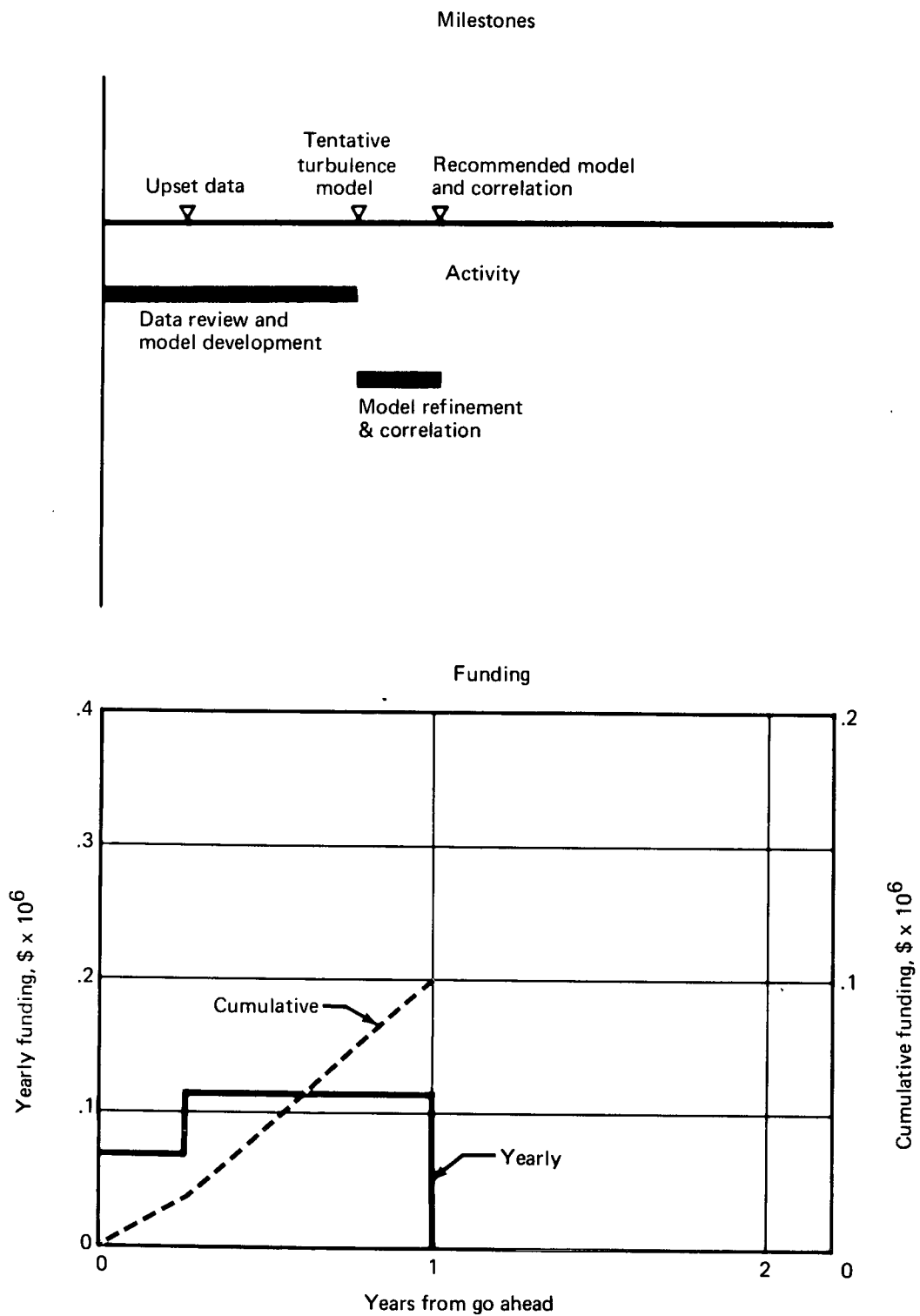


FIGURE 109.—IMPROVED ATMOSPHERIC MODELS-COST AND SCHEDULE

Cost and Schedule

As shown on figure 110 the expenditure of approximately \$200,000 over 18 months can accomplish the stated goal. This includes a piloted simulation verification of the control system implementation on a representative ATT vehicle.

Improved Aeroelastic Methods for Flight Controls Analysis

Potential Payoff

In the flight control design on a new configuration any uncertainty in the ability to predict airplane behavior leads to conservative design. The aeroelastic characteristics significantly impact longitudinal balance considerations, e.g., empennage size and wing placement, as well as control effectiveness. All of these items have major weight impact. Therefore, by developing improved methods for timely estimates of aeroelastic effectiveness the airplane size may be reduced, the control system may be simpler, involving fewer or smaller surfaces, with the subsequent performance benefits.

State-of-Readiness

The sophisticated tools used in airplane structural design and analysis are well understood, however, it is necessary that a less complex tool, hence more timely, be developed from these for use in flight control design. All of the necessary elements are available, requiring only the emphasis of a study such as this.

Recommended Action

This item should be undertaken by the NASA or by a representative of the aircraft industry experienced in the design of large flexible airplanes.

The study should begin by examining an existing airplane for which flight test and wind tunnel data are available on aeroelastic effectiveness, e.g., control reversal speeds. These real world data can be used to simplify and/or improve the estimation techniques. The following milestones highlight the recommended action:

- Select a base airplane—existing airplane with available wind tunnel, flight test, and structural data.
- Determine the ability to predict flight test observed aeroelastic phenomena.
- Develop a simple, quick, best estimate tool for flight control use.
- Verify its usefulness with a comparison of predicted and actual aeroelastic behavior.
- Determine the sensitivity of airplane balance and flight control design to the accuracy of the method.

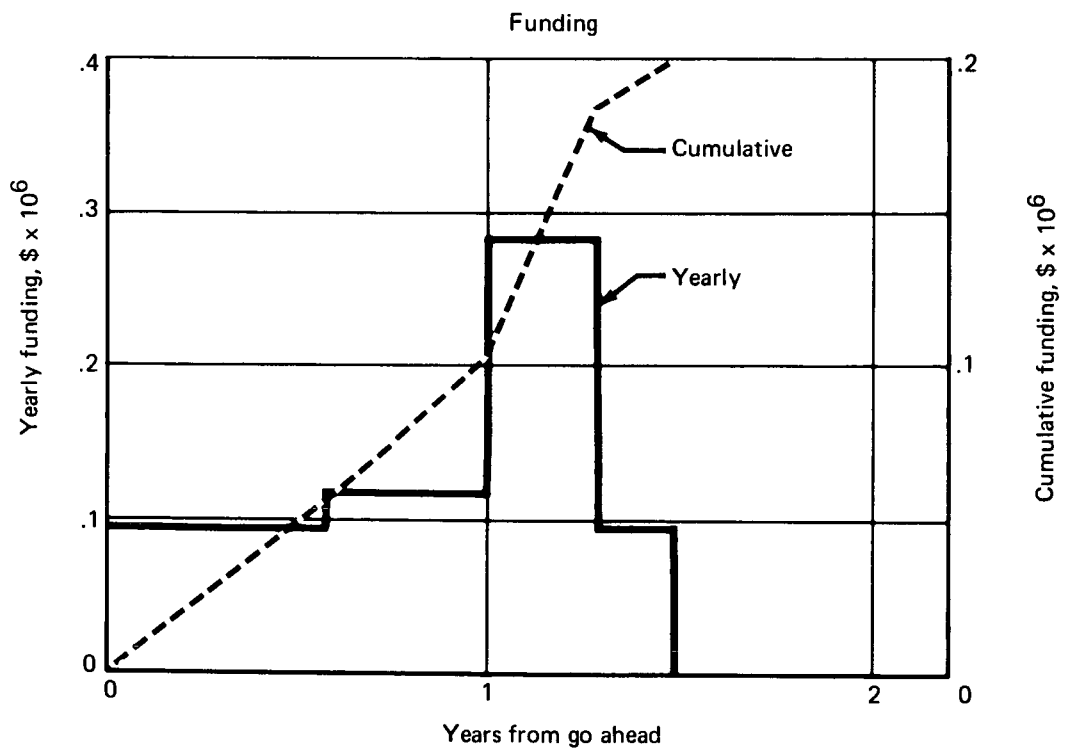
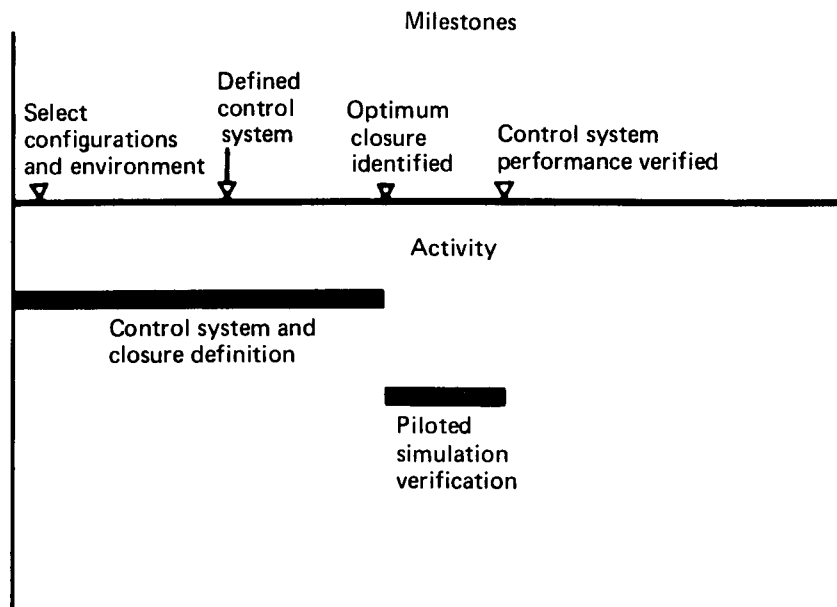


FIGURE 110.— FLIGHT PATH CONTROL—COST AND SCHEDULE

Cost and Schedule

The study goals require funding of approximately \$100,000 for one year as shown in figure 111. This estimate includes the required engineering and computing support for the duration of the study.

Advanced Navigation Systems Development

Potential Payoff

Navigation systems capable of guiding an airplane along paths independent of the position of ground-sited navigation aids are now being specified. Such systems, particularly if they include the ability to control the airplane's position accurately with respect to time, promise direct benefits in en route spacing, maximum usage of runways, and a contribution toward optimizing the total air transportation system effectiveness. To fully realize this potential, it is necessary to study the combination of ATC operational techniques and airborne navigation system capabilities. This would provide assurance that the installed systems include those capabilities needed for ATC capacity improvement. A range of navigation system mechanizations would be defined together with trade data for evaluating performance, cost, and implementation complexity. The time accuracy of aircraft delivery to routing points (waypoints, approach fixes, runway thresholds) using new longitudinal/autothrottle control laws together with advanced navigation and guidance techniques would be determined. The accuracy achievable is a key factor to many of the concepts considered in the upgraded third generation ATC system and the fourth generation ATC studies.

In addition, the attainment of on-the-ground guidance for rollout and taxi is essential to the implementation of the ultimate Category III automatic landing system.

State-of-Readiness

Area navigation systems without time-referenced control and some guidance concepts have been evaluated in activities by airlines, equipment manufacturers, and governmental and inter-industry organizations, with somewhat inconclusive results as to best procedures and equipment to utilize. Extensive simulation studies have been made of some navigation and guidance techniques needed for 4D area navigation, and the analytical studies have indicated potential airspace capacity increases. Some on-the-ground guidance research has been accomplished with autonomous position sensing devices and considerable experience is available with systems emphasizing new equipment installed along the runway.

Obviously, substantial work has been accomplished in the navigation systems field. However, a major portion may be considered a piecemeal effort and this is the deficiency of concern. An integrated avionics package that is cost effective in commercial airline use and is compatible with the expanding ATC function must be provided.

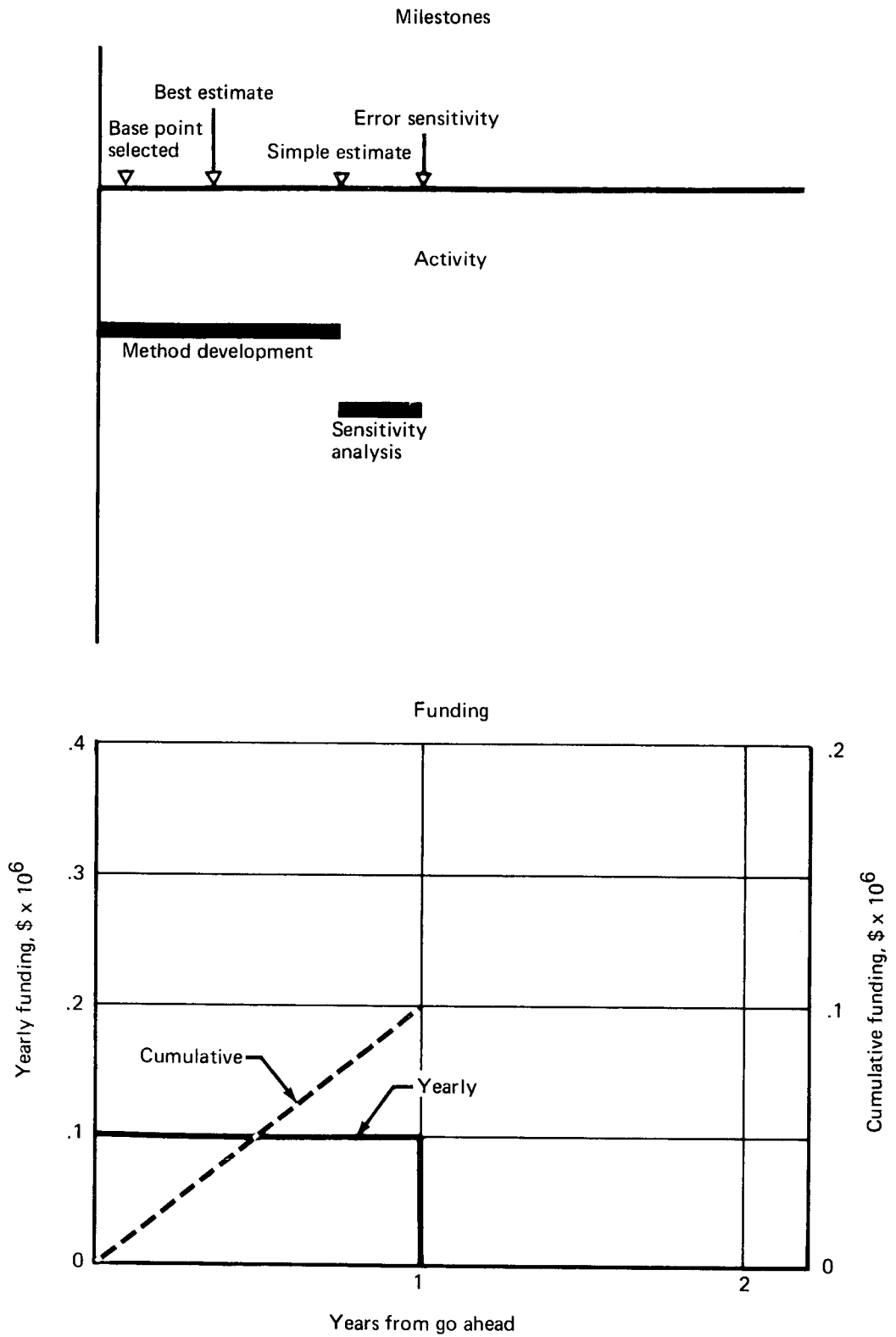


FIGURE 111.— IMPROVED AEROELASTIC METHODS—COST AND SCHEDULE

Recommended Action

NASA should initiate a program with industry to accomplish the following:

- Develop and evaluate, analytically and by simulation, ATC operational techniques which make use of time-constrained area navigation systems of varying levels of capability.
- Define a set of alternative navigation systems composed of a dead reckoning computation augmented by radio navaid data. The inertial dead reckoners should include gimbaled systems, strapdown systems, and vertical gyro/directional gyro packages. The radio navaids should include VOR/DME, OMEGA, MLS, and, possibly, LORAN. The augmenting algorithm should range from Kalman filter through less rigorous variants to simple position and velocity updating.
- Perform analyses and simulation studies to develop autothrottle/pitch axis control laws for a selected airplane. These control laws to use along-track position error signals and ground speed error signals as inputs.
- Mechanize selected systems from the above effort into computer simulations for the development of comparative performance data, and develop trade data on airborne navigation techniques, relating capability to hardware complexity, availability, and cost.
- Develop a flexible airborne test system from currently available hardware, and perform flight tests to verify and improve analytical conclusions on navigation capabilities, operational procedures, and benefits.
- Develop a number of operational concepts for on-the-ground guidance and evaluate their capacity as a function of traffic model and sensor characteristics. Analyze the use of onboard airplane systems, alone and in conjunction with single ground installations, to provide the necessary taxi guidance function and recommend a system for implementation.

Cost and Schedule

A two-phase program plan is identified in figure 112. The work is scheduled for a two-year period and requires total funding of \$5.6 million.

Advanced Digital Systems Applications

Potential Payoff

The objective is to define criteria and functional requirements, design and procure hardware, and accomplish evaluation testing for onboard digital systems. The payoff is difficult to isolate and to define in conventional terms of dollars, drag, or pounds; however, these equipments complement other flight and ground avionic hardware and improvement thereof is highly essential to permit attaining the maximum overall gain in the ATC congestion situation.

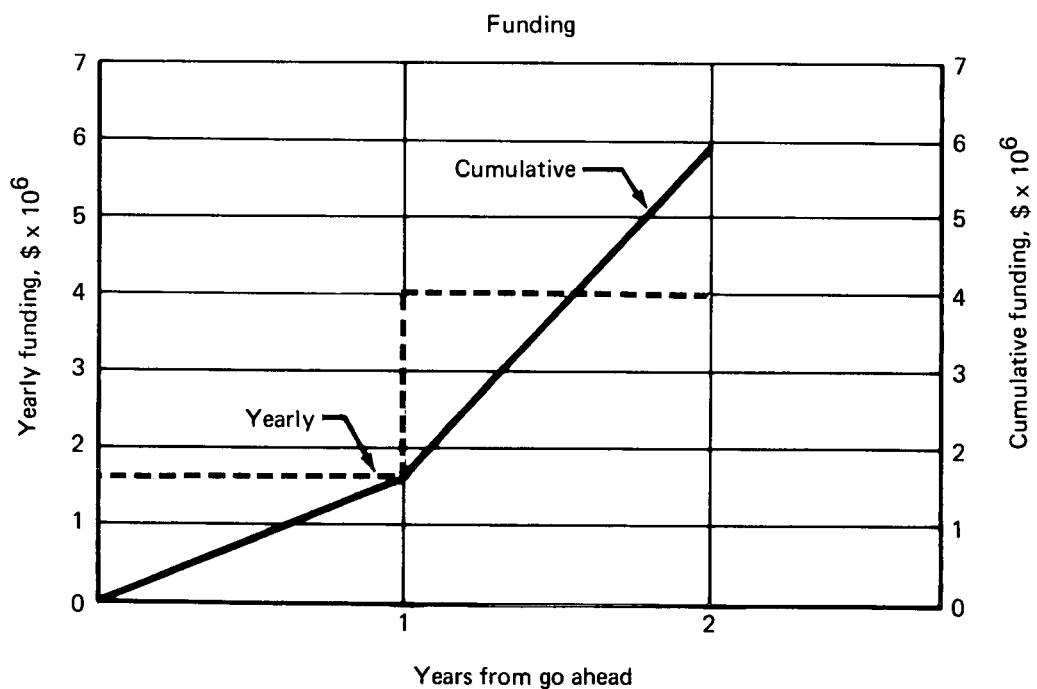
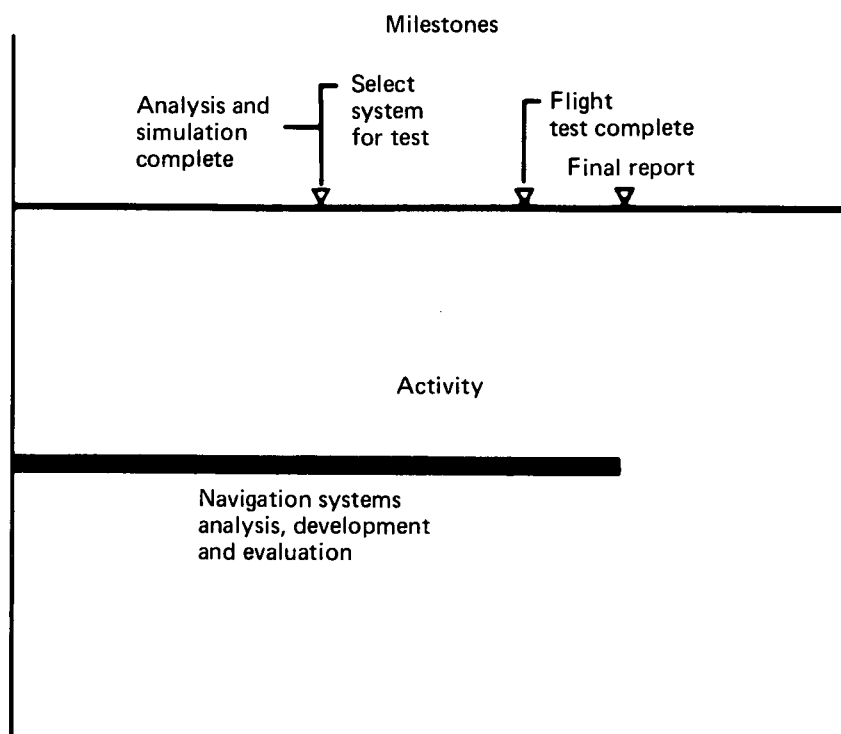


FIGURE 112.— ADVANCED NAVIGATION SYSTEM DEVELOPMENT PLAN

State-of-Readiness

Preliminary theoretical studies have been accomplished to evaluate digital data transmission techniques. Limited experimental work has been completed in the specific areas of split phase bi-polar, return-to-zero, and nonreturn-to-zero systems for this particular application.

Systems monitoring is currently accomplished by a variety of techniques: display panels, built-in test equipment that operates communicators, and airborne integrated data systems (AIDS). The integrated systems monitor (ISM) technique, a digitally organized arrangement with redundancy and degraded mode operation, has not been applied in current airplanes.

The capability to satisfactorily manage airplane movement in the expanding ATC environment is directly dependent on the availability of suitable digital techniques. The ability to rapidly handle large quantities of data in a cost effective manner is essential to commercial operation.

Recommendation

NASA should initiate development programs to be accomplished by industry as follows:

- Onboard Digital Data Transmission
 - Conduct theoretical studies to define a set of alternative transmission techniques. The modulation technique, sample rate, message structure, transmission line characteristics, efficiency, interface requirements, and reliability complexity considerations should be examined.
 - Design and build candidate system hardware including equipment necessary for interfacing with associated state-of-the-art digital avionic equipment.
 - Accomplish laboratory tests in a simulated ATT environment including both normal and severe EMI conditions.
- Integrated System Monitoring
 - Establish candidate parameter lists, parameter characteristics, and associated requirements.
 - Configure candidate systems including a central computer, essential data acquisition units, digital flight data recorder, flight data acquisition units, displays, and associated control panel, and monitor data acquisition units.
 - Evaluate candidate systems to identify the system or combination which meets requirements in the most cost effective manner.
 - Prepare detailed functional specification for the selected system.

Costs and Schedule

A program plan is shown in figure 113. The activity is scheduled over a 24-month period which estimated funding of \$2.1 million. Either of the two identified segments of the program could be conducted separately.

Advanced Flight Deck Development

Potential Payoff

Advancement in the integration of flight deck functions is necessary to ensure safe and effective man/machine utilization in the ever-increasing complexity of the associated ATC environment and to attain this gain with minimum performance and economic penalty.

The payoff in this area is difficult to determine in terms of the airplane alone. The situation must be viewed as a part of the overall congestion and noise problem that plagues civil aviation today. It is expected that flight deck advancements will effect improved air traffic safety and contribute to relief of congestion and noise.

State-of-Readiness

The current status of proposed development items is as follows:

- **Flight Deck Integration**
A methodology has been established that should lead to an optimum ATT flight deck. Computer-driven electronic displays are in various stages of development and test. The electronic attitude director indicator (EADI) has been flight tested. The multifunction display (MFD) and pictorial navigation display (PND) have undergone simulator testing. The control display unit (CDU), or navigation data display, has not been sufficiently tested. Use of these systems has been explored in some detail for the SST prototype. Questions remain on ATT or other airplane application and on suitability and practicality of color and cathode ray tube (CRT) alternates.
- **Indirect Optical Viewing**
This concept is an outgrowth of the wide field of view heads-up display systems used by military aircraft. High level optical performance is inherently available. As a result of work initiated during the SST program it is concluded that a prototype system, incorporating all correct optical principles for the application, can be built.
- **Independent Landing Monitor (ILM)**
Two types of ILM are currently practical: one which utilizes radar beacons along the runway, and the other which employs an airborne perspective radar. Both present a perspective view of the runway on a CRT display. Simulation and flight tests of the airborne radar system have demonstrated its utility for attaining and maintaining correct runway alignment. Two ILM systems are currently being test flown by the USAF. Contractor tests have established that a mix of perspective view, and appropriate symbology is more meaningful than either separately.

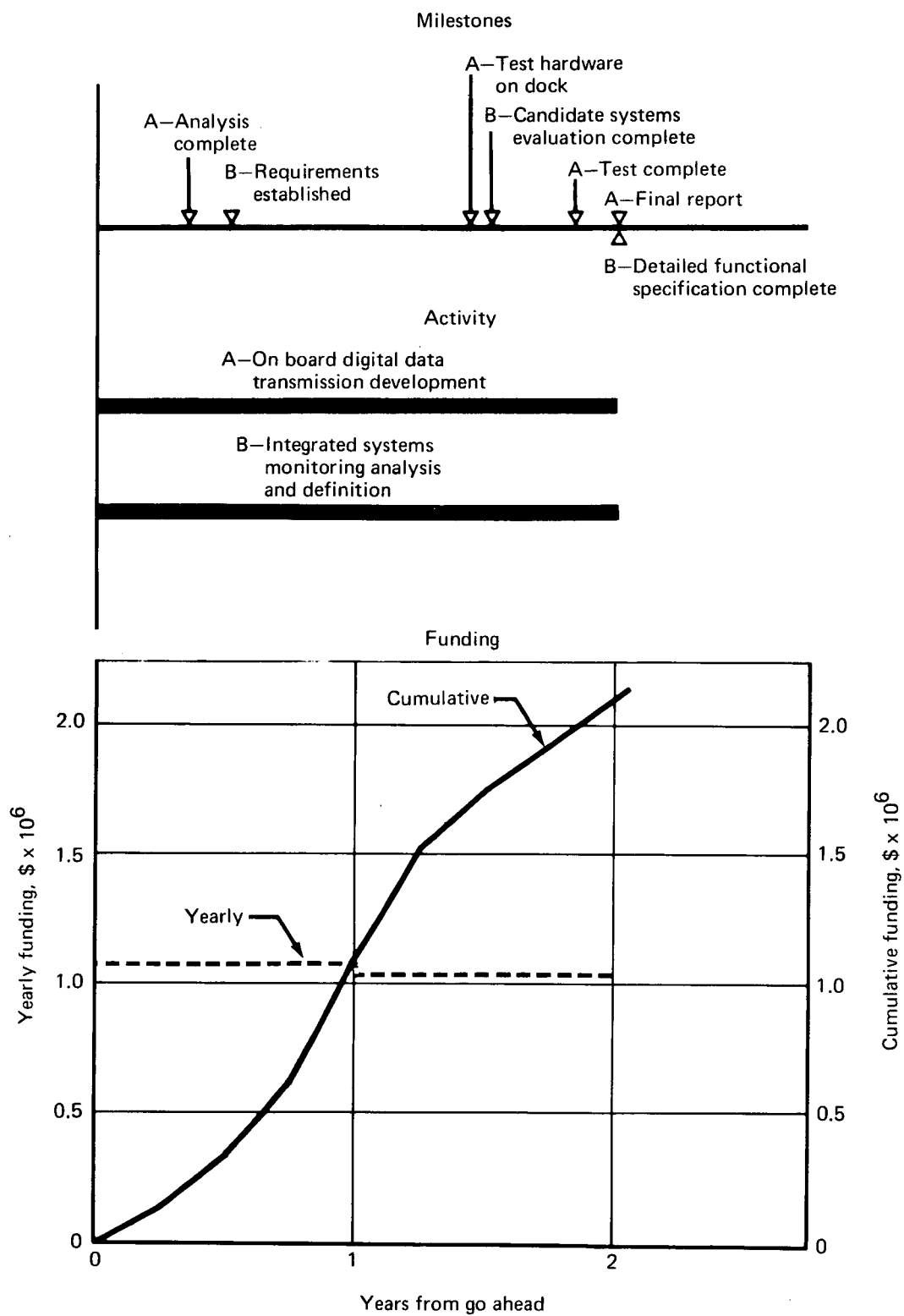


FIGURE 113.—ADVANCED DIGITAL SYSTEMS APPLICATIONS PROGRAM PLAN

A general deficiency in the crew's ability to manage airplane flight can be expected with increased traffic congestion. It is mandatory that the flight deck be optimized for maximum crew efficiency.

Recommended Action

It is recommended that NASA, with industry support, define work statements for the development programs below. NASA should then fund and contract work to industry.

- **Flight Deck Integration**
Define criteria/requirements for operation in high-density airspace, all weather, low noise environments. Establish required display and control system flexibility to accommodate complex flight plan data in multiple flight regimes, including information content, formats, and interface requirements between airborne and ground equipment. Establish an analytical data base for the certification process. Measure the operational performance of the aircrew-flight deck combination in the simulator.
- **Indirect Optical Viewing**
Define and procure a prototype system and install in a small aircraft for evaluation. Accomplish analysis and development using a full scale mockup to integrate the optical system into the flight deck system, if earlier flight tests so warrant. Define, develop, procure and certify a system suitable for jet transport airline operation. Subsequently an in-service evaluation could be required. The system to be studied is shown schematically in figure 114.
- **Independent Landing Monitor**
Accomplish analysis to establish relative merits of onboard versus ground-based equipment. Refine symbology and signal conditioning of reference signal, particularly for radar contrast, i.e., runway versus grass, dirt and sand. Establish monitoring accuracy requirements and standards of use. Design, procure, and test system through certification and in-service demonstration.

Cost and Schedule

A program plan for accomplishment of these developments is shown in figure 115. The work would be accomplished over a 6-year period, and funding of \$6.9 million would be required. Each element; flight deck development, optical viewing system, or instrument landing monitor could be accomplished individually. In addition, each element could be phased into essentially one-year increments.

Low Cost Inertial Sensor System

Potential Payoff

The objective is to develop a low cost inertial sensor system and demonstrate system applicability to commercial airplanes. Broad application in overwater navigation, area navigation, dynamic and predictive data display, stability augmentation, and landing guidance

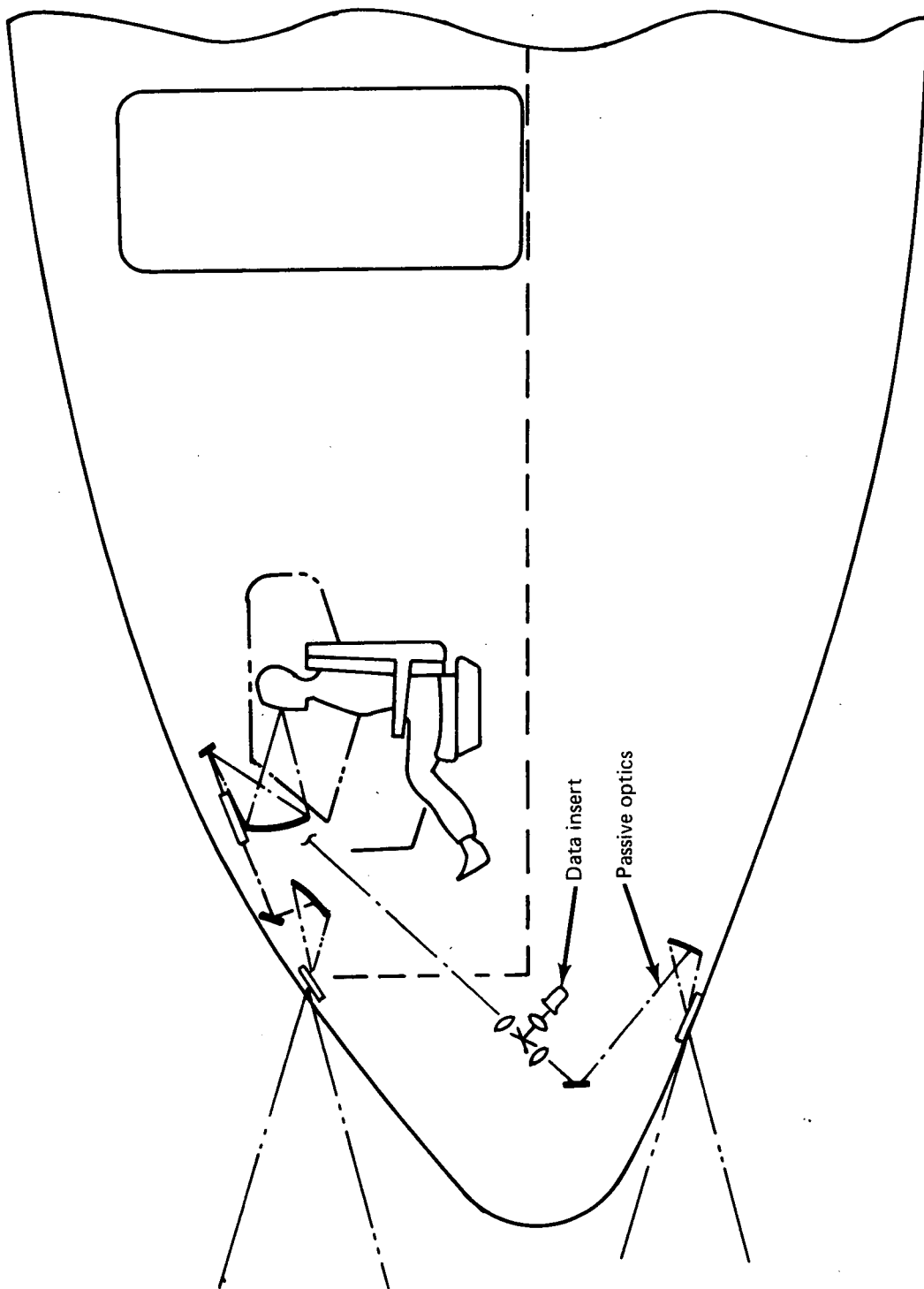


FIGURE 114. – INDIRECT OPTICAL VIEWING SCHEMATIC

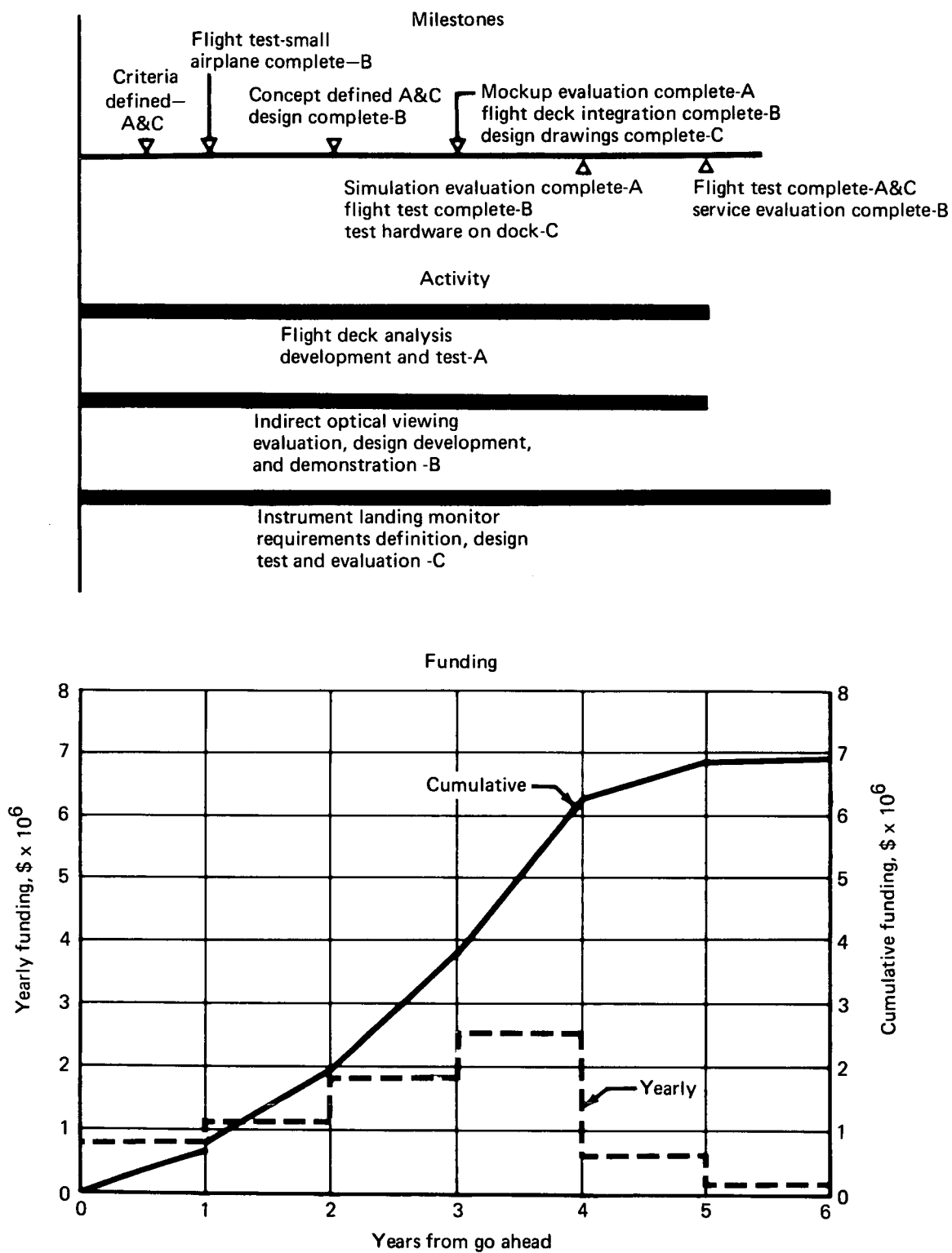


FIGURE 115.—ADVANCED FLIGHT DECK DEVELOPMENT PLAN

systems indicates substantial weight and initial cost reduction potential. A unit weight and cost reduction of 70 pounds (31.7 kg) and \$65,000 is anticipated. The advanced technology transport requires four units for a 280 pound (126.8 kg) weight reduction and a \$260,000 initial cost saving.

State-of-Readiness

Current ARINC 561 and 571 systems use mechanical gimbals and cost approximately \$100,000/unit. Strapdown inertial system concepts of low weight and anticipated low production cost are currently under development by the electronics industry. These units eliminate gimbal use, resulting in a greater computation burden and in reduced system accuracy. With increased use and reduced cost of digital computers, an acceptable overall system could be put together with sensors of low accuracy. It is anticipated that sufficient data are available from suppliers to initiate an error analysis and concept evaluation.

The obvious deficiency to commercial airline application is high cost and excessive weight.

Recommended Action

It is recommended that the NASA initiate action to fund the three-phase program described in figure 116. The first phase, primarily analytical, would be accomplished in one year. The results of Phase I would determine the detail nature of Phases II and III.

Cost and Schedules

The planned development program, scheduled over a 3-year period, would require funding estimated at \$2.45 million.

Air Traffic Control Terminal Operations and Airborne Requirements Study

Potential Payoff

Two major operational factors affecting commercial aviation today are:

- Community Noise
- Terminal and Airport Congestion

The noise problem is being attacked through engine and nacelle research (reduction at the source) and improved operating techniques to reduce the amount of noise reaching the community.

The congestion problem must be met by new methods of optimizing the use of existing airport real estate, especially for those saturated metropolitan hub airports which cannot expand. This involves improvement of air traffic control (ATC) and aircraft capability for higher flow rates per runway and for closer parallel runway operation. Improved allocation and more efficient use of airspace in high density regions is also necessary.

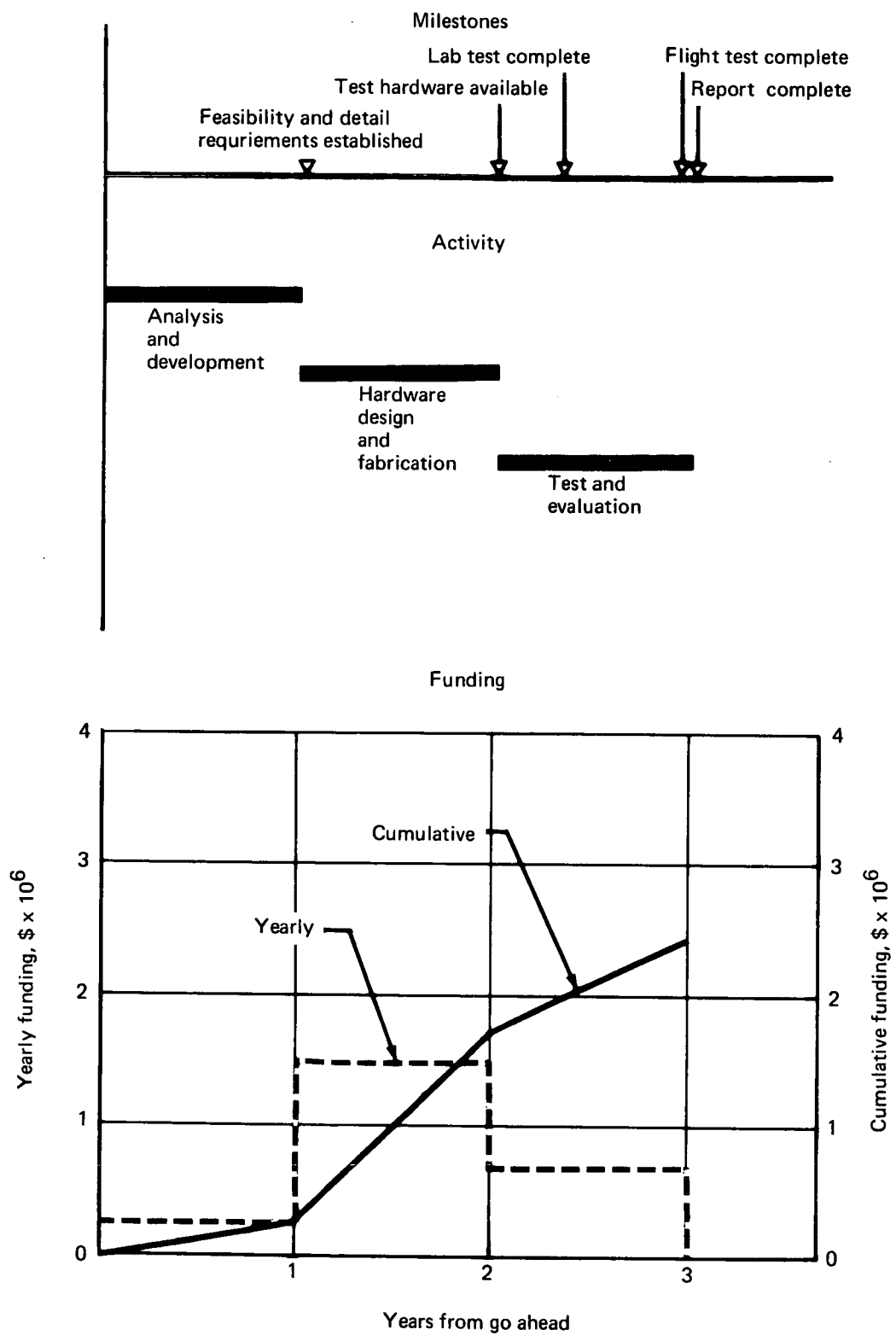


FIGURE 116.—LOW COST INERTIAL SENSOR DEVELOPMENT PLAN

It is expected that a terminal operations requirements and an airborne systems definition study would contribute substantially to the alleviation of the noise and congestion problem.

State-of-Readiness

Present jet transport guidance and control technology is exemplified by the Model 747, which has a fail operative triplex autoland system and triple inertial navigation and autopilot capability. It is feasible to add computation capacity, interfacing hardware, and appropriate software packages to provide radio augmented inertial navigation for precision area navigation in three dimensions and storage of waypoint and command altitude data for accurate flight path control. Such a combination would have more capability for use with advanced terminal area control techniques than present ATC is able to utilize effectively since the present, so-called third generation ATC system does not include terminal area radio navigation routes and procedures for use that would expedite traffic management.

Between 1975 and 1980 the automated radar terminal system (ARTS) III and ancillary equipment with computer assisted metering and spacing should be in operation. From that time the ATC capability to direct high flow rates should exceed the aircraft capability to comply safely in IFR conditions unless programmed updating to the aircraft equipment is accomplished. For example, curved approaches are necessary to high flow rates and steep descents are required for noise abatement and traffic separation reasons. The combination of steep and curved descents in IFR weather with sufficient precision for safe traffic separation and within passenger comfort constraints requires a definite advance in the state of the art in airborne navigation, guidance, and control. Such an advance should include: three-dimensional automatic path guidance with the eventual addition of precision schedule keeping (time navigation); a closer coupling of guidance and control systems with greater authority vested in the automatic flight control system; and advanced flight deck controls and displays for safe monitoring and management of flight operations in the more demanding terminal control environment.

Recommended Action

It is recommended that NASA solicit industry support to prepare work statements for the complementary analytical studies described below. Work statement preparation should be followed by NASA funding and contract to industry. The two identified tasks should be accomplished as a parallel effort by an airframe manufacturer.

Terminal Operations Requirements Study.—The broad objective should be to further the understanding of the interrelationship between airplane, airport, ATC, and intermodal interfaces for the 1980 postulated environment in order to define realistic supplementary design criteria for the airplane. The primary emphasis should be on the airplane and the associated onboard systems requirements. The actual preliminary definition of these airborne systems should be done in a parallel study effort.

Two assumptions in the environment definition should be used to keep the number of variables within bounds:

- To postulate the 1980 ATC terminal control environment based on interpretation of results of the DOT 4th Generation ATC Study Contract being performed by the Contractor and to use this prediction as a given environment. The implementation plan would be most useful in this regard.

- To assume the airport taxiway and runway configuration has a fixed geometrical structure of which high speed drift-off zones and close spaced parallel runways are a part.

The postulation should be that the traffic flow acceptance capacity of the ATC/runway systems is higher than can be utilized by today's airplane technology.

The study should then undertake to determine what the airplane characteristics must be and what the operation requirements are to optimize airport traffic flow rates within the constraints of safety, passenger comfort, pilot workload, community noise and emission, and minimum fuel and time expenditure. The principal items under investigation should be: the guidance and control technology necessary to utilize approach profiles which are the most efficient transitions from cruise path to landing gate in all weather conditions; and the flight management processes, both automatic and manual, which are necessary to control and monitor these functions safely and efficiently.

Topics that should be studied are approach, land, rollout, taxi and park, turnaround functions, and takeoff/go-around. The approach and landing phases should have the most attention.

The study results should include:

- Airplane performance requirements in the terminal area, particularly guidance and control response capability to advanced ATC, including low visibility conditions.
- Identification and preliminary specification of all necessary interfaces between the airplane and the outside world which may include:
 - ATC Surveillance Function
 - ATC Control Process
 - Terminal Navigation Aids
 - Terminal Landing Aids
 - Independent Landing Monitor
 - Communications
 - Turnaround Techniques
 - Onboard CAS, if any.

Airborne Systems Definition Study.—The broad objective should be to understand the relationships between airborne system requirements and airborne avionic/mechanical systems specifications, and the methodology by which such relationships could be established on a meaningful basis so that hardware/software developments could proceed.

Airborne system functional and performance requirements, modified by applicable safety, passenger comfort, and regulatory criteria, should be categorized to provide the basis for development of a summary matrix of functional/performance requirements for each system and an understanding of the factors contributing to the most stringent performance requirements.

A rationale should be developed to define the level of time sharing or integration of functions in accordance with flight critical/noncritical requirements, crew effectiveness, and optimal design technology criteria for achievement of realistic system specifications. The study should proceed to develop data flow schematic diagrams, to define airborne system interfaces and to accomplish mechanization trades. These trades should be augmented by consideration of physical constraints such as weight, power, antenna requirements, initial cost, and maintenance costs resulting in the selection of a specific mechanization for development into system hardware/software specification.

Costs and Schedules

A program plan is shown on figure 117. Each task is scheduled for completion in 12 months and requires \$430,000 and \$500,000 funding, respectively.

EQUIPMENT AND FACILITIES

Throughout the Advanced Technology Studies each technical area was reviewed to establish the need for developmental equipment, including new or modified existing flight vehicles, and new or revised facilities. This was accomplished in the framework outlined by the Statement of Work (SOW). The SOW established the objective that equipment and facilities should be identified that are necessary to bring the state-of-readiness to a status that industry could commit specific advanced technologies to a major commercial airplane program. That objective presents more far reaching implications than just verifying the technical feasibility of specific advanced technology items.

Because of the large financial risk involved on a new airplane program, basic prerequisites must be met before commitment can be made. At least three organizational groups are involved; the airframe manufacturers, the potential airline customers and government regulating agencies. The airframe manufacturers management (and major subcontractors) must not only be assured that a new technology is technically feasible, but they must be assured that the application of the technology is acceptable to the ultimate customer, the operating airlines, and to government regulatory agencies.

To achieve the required assurance of acceptability, it has historically been necessary to pursue a demonstration approach in a manner that all three organizational groups were involved in the confidence building process. This has been true whether it involved a complete new airplane concept, or a limited application of discrete technology. In all cases the demonstration was performed on a transport of sufficient size that airline pilots, maintenance and ground service personnel could evaluate the impact on their operational activities. In addition because the demonstration airplane was in most cases operated on parts of the national terminal/route system, regulatory agencies also participated. All three interested organizations

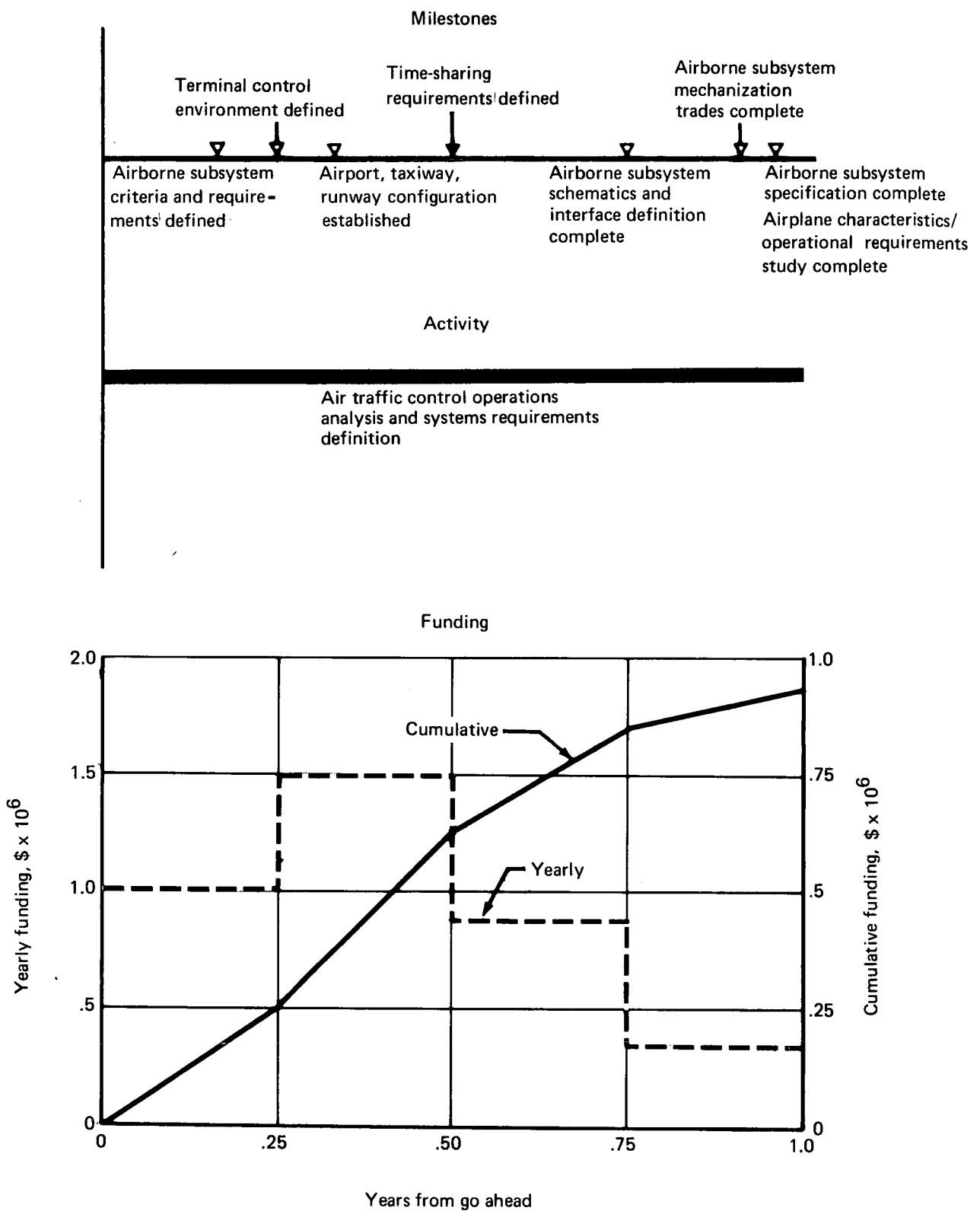


FIGURE 117.— ATC/OPERATIONS STUDY PLAN

were therefore involved, and following the stipulated demonstration, the confidence needed to commit and accept the applicable technology was available.

The above is considerably more involved than mere technical verification, as would be the case for laboratory or limited nonoperational flight testing. The philosophy followed in defining needed equipment and facilities during this study has, therefore, been to ensure that all organizations affected by a program commitment would be involved during technology demonstration. Those equipments and facilities are identified below.

Equipment

The current problems are cost effectiveness, reliability, aircraft noise and congestion. Where required, demonstration flights of designs using advanced technology to improve or solve these problems must, in most cases, be carried out under at least simulated typical airline conditions by airline personnel to assure an adequate demonstration. Advanced systems and designs that can pass this type of demonstration and thereby satisfy the questions of the user, manufacturer, and the FAA will be readily accepted for incorporation into new aircraft designs.

Examination of the technical areas and technology development programs recommended in this report revealed that emphasis should be placed on the use of modified existing commercial aircraft for the required flight demonstration. Use of scaled or special experimental type aircraft should be used on a selective basis as interim development tools for technical verification prior to incorporating on the ultimate demonstration vehicles. This will provide the most economic method for gaining needed test data and providing the confidence for commitment by all parties concerned. Where inflight testing is required to provide needed technical data, or flight demonstration is required to provide program commitment on individual technology areas, such provisions are called for in the individual programs described in the previous sections. The estimated funding and schedule for those programs are also included in each applicable recommended program. A summary of those needs is provided below for each technical area.

Aerodynamics

- Flight Test/Wind Tunnel Correlation—flight test required
- Roughness and Excrescence Drag (transonic speeds)—flight test
- Sonic Boom at Cruise Slightly below Mach 1.0—flight test

Structures and Materials

- Filamentary Composites—In service flight test
- Active Control System—Validation flight test

Power Systems

- Demonstrate Quiet Nacelle Design—flight test
- Demonstrate Advanced Engine Design—flight test
- Advanced Hydraulic System—In service flight test
- Advanced Landing Gear Design—In service flight test
- Carbon Brake—In service flight test
- IEG—In service flight test
- Noise Abatement Flight Procedures—flight test
- Subjective Noise Criteria Improvement—flight test

Control of Flight

- Indirect Optical Viewing—Flight test verification
- Independent Landing Monitor—Flight test verification
- Advanced Navigation System—Flight test validation
- Low Cost Inertial Sensor System—Flight test verification

Facilities

Examination of the proposed technology programs has indicated areas where new or improved facilities are considered desirable to assure the most economical advancement of technology items. These facilities are listed below, under the appropriate technical area, along with the purpose for each item noted.

Aerodynamics

- A definite need exists for an interference “free” transonic test section—To ensure accurate aft body closure test results in the transonic regime.

Structures and Materials

- Large size environmental testing chambers which are required to efficiently apply heat, cold, moisture, pressure and fatigue type cycles to test structure with a high degree of accuracy and reliability. Present machines have limited capability and poor reliability.
- Sonic fatigue test chambers using actual engines and realistic sound spectrum.

- High speed fatigue test machine for combined loadings—An erector set design that can be fitted to an appropriate range of test structure.
- Test facility for large diameter, long cylinders in compression or combined loading—to test for general structure instability.

Power Systems

- Improved power system simulation and measurement accuracy for powered aerodynamic model wind tunnel tests—The problem of simulating inlet and exhaust conditions on jet powered wind tunnel models has been unresolved for years; improved aircraft designs will always be questionable until a solution is found.
- Large scale, high bypass ratio engine test facilities—To evaluate engine transient operational characteristics (currently limited to flight test).
- Noise testing will require laboratory facilities emphasizing indoor testing of scale models of engines, jets, fans, compressors, burners and turbines in appropriate combinations with inlets, discharge ducts and nozzles. Large anechoic rooms are needed to provide testing around the clock, free of problems due to weather, noise interference and community noise complaints. A reliable method will be needed to account for the acoustic effects of relative velocities of the airplane and the propulsive flows, Acoustic wind tunnels, sleds and tracks and rotating rigs should be evaluated to determine their relative merits. Flyover noise measurement systems should feature portability, minimum test preparation time and on-line data reduction for immediate assessment of the noise levels.

Control of Flight

- Flight controls development rig—To provide verification of advanced flight control system design.
- Pilot compartment mockup and flight demonstrator—To evaluate the problems and advantages of an indirect optical display system.
- Onboard digital data transmission demonstrator—To establish the advantages of this proposed system under the actual conditions found in an airplane. (Transient magnetic fields, etc.)

CONCEPTUAL APPROACH

In conformance with the rationale and conclusions described in the previous Equipment and Facilities section, the Contractor recommends that advanced technology demonstration vehicles be pursued in a form that emphasises the use of modified existing commercial transports. Specifically, it is recommended that a building block concept be followed with one or more existing transports being modified on a gradual basis as discrete technology-items

become available. As foreseen, this concept can involve the application and demonstration of technologies as a function of applicable development schedules, as follows:

Concept Description

Initially, one or more transports can be modified to include some of the secondary structure and secondary control surfaces fabricated from advanced composite material. This is already underway as evidenced by the use of a composite foreflap and a composite spoiler on the 707 and 737 respectively. These would be applied to the demonstration transport along with selected advanced navigation and flight control items that early schedules will permit near term installation. The above could be accomplished by 1973. By 1975, the powered wheel and additional advanced composite structure items including doors, empennage and nacelles can be added. Major advanced composite structural items, including body segments and wing box structure, along with selected active control surfaces and subsystems can be added during 1976. The 1976 modification can include adoption of the supercritical airfoil and addition of body fairings to simulate area ruling. Advanced low noise/emission nacelles and all encompassing navigation and flight control advancements can be added during the 1977-1978 period. Assuming the integrated engine generator program continues to be attractive, it can probably also be added during the 1977-1978 period. The concept should include use of further modified F-8 or other smaller aircraft, on a selective basis, to verify basic technical approaches prior to incorporation on modified transports.

A schedule for the modified transport portion of this concept is shown by figure 118. By 1979, the full impact of the entire recommended research and development program can be reflected in the modified transports. These transports will be valuable for building the confidence in the acceptability of the technology advancements that are included.

The above described building block concept would include at least simulated airline operations using a combination of NASA, operating airline and airframe industry flight and ground crews. Historical experience indicates the operating airlines would be cooperative in this approach. Because demonstration would occur, at least in part, over scheduled airline airway and terminal networks, the FAA would also participate. When specific installed modifications had reached the point where high confidence was demonstrated, scheduled service by one or more operating airlines for cargo followed by passenger service can be scheduled into the program. Evaluation of passenger response, as well as public reaction, can be made.

The size of the modified transports should be held to the 737, 727, or DC-9 categories of existing transports, to minimize the modification and operation cost. Basic systems are available for those aircraft and historical manufacturing and operations cost data is available, against which the benefits demonstrated by the modified transports can be measured.

The building block concept will provide unique benefits that are only partially attainable through other approaches. These include:

- Participation by all government and industry parties interested in the confidence building process.
- A direct way of publicizing the efforts being made to improve the aeronautical technology image.

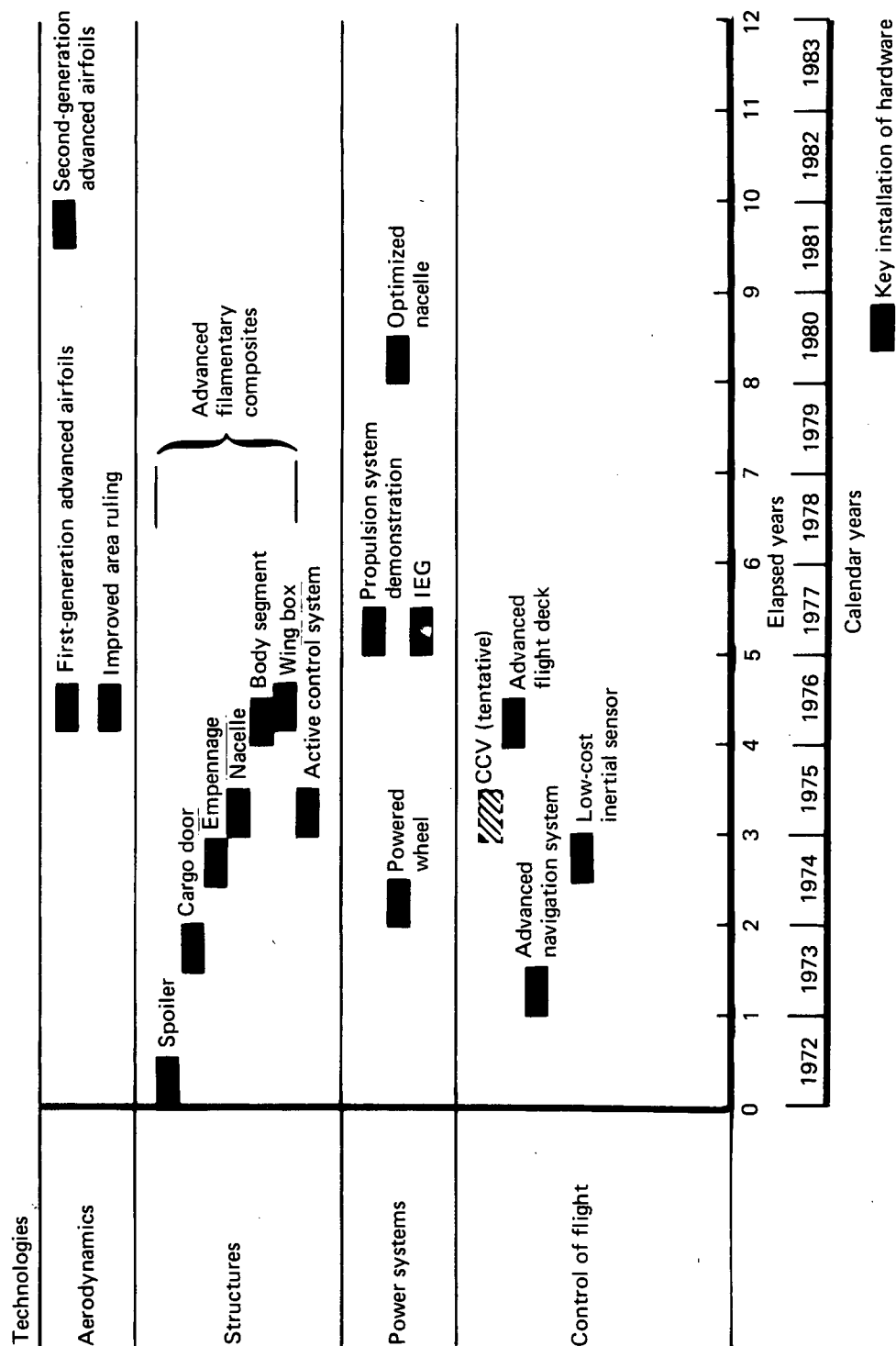
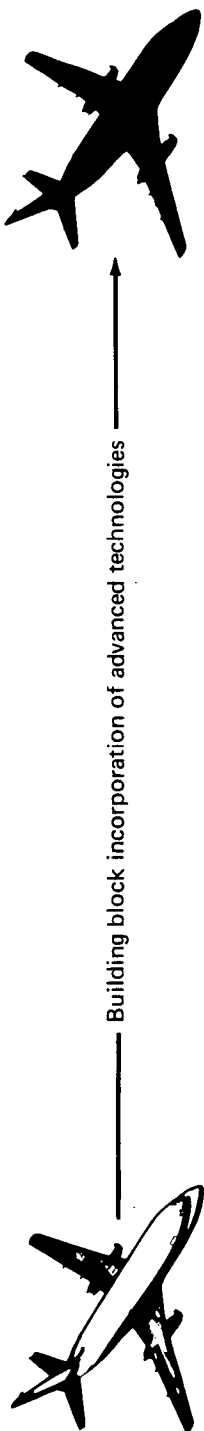


FIGURE 118.— BUILDING BLOCK CONCEPT IN SERVICE DEMONSTRATION

- Demonstration of the acceptability of all the major program items by 1980, on an airplane that is sized for, and familiar to operating airlines and the public.
- Incremental demonstrations up to 1980 of items that, in some cases, can be adapted to existing fleets.
- Experience, available to the industry, that reflects the definition and solution of currently unknown problems in the design, fabrication and operational implementation cycle for advanced technology application.

Recommended Action

It is recommended that the NASA issue study contracts of approximately 6 months duration that would be directed at the firm definition of the content, schedule and cost of a comprehensive building block demonstration program. This is to be followed by issuance of contracts to accomplish the demonstration concept implementation.

Cost and Schedule

Two initial program definition contracts are recommended to be funded at approximately \$250,000 each over a six month period. Firm costs for the demonstration program would result from the initial study contracts.

CONCLUSIONS

Study of the benefits to be derived from use of advanced technology was conducted using specified goals and a viable transport configuration suitable for operational use in 1977, as the measurement baseline. Individual technology candidate items were applied in a manner that provided a realistic evaluation of this technical impact and their effect on airplane and lifetime operating cost. This approach provides credibility to the following study conclusions.

GOALS

The reduced noise emissions, congestion, and cost goals established by the joint DOT/NASA CARD study team are severe but attainable. To attain those goals in an atmosphere of increasing foreign competition that is largely government-supported, will require the attention of and joint action by United States government agencies and industry. The economic posture and labor employment level of this country during the 1975 to 1985 period are at stake.

POTENTIAL PAYOFF

Each of the technology areas was found to offer potential contribution toward meeting the goals of noise/emission reduction, congestion reduction and reduced cost. Major contributors were:

- **Design Integration**
Attractive noise and congestion reduction potential is offered by advanced unconventional configuration approaches. The potential for reducing airline maintenance and delay costs was also identified.
- **Aerodynamic Configuration**
Wind tunnel testing should be continued to provide confidence in the aerodynamic performance and costs estimates made for commercial aircraft that use supercritical airfoil and area ruling technology. In addition, a further 0.05 improvement in critical Mach number is an attainable goal by 1980.
- **Structures and Materials**
Advanced composite structure offers a potential takeoff gross weight reduction of up to 15% for a 1981 operational airplane and up to 25% reduction for a 1985 version. It also offers significant cost reduction potential when airplanes are sized for its application. Although bonded aluminum does not offer as large absolute weight reduction potential, it does offer a larger return for the required research and development investment.
- **Power Systems**
Incremental noise reduction to approximately 10 EPNdB below current FAR Part 36 can be attained by 1981, with a 15 EPNdB reduction by 1985. High risk is involved for both periods with probable weight penalties for the 1981 value. A

concentrated research and development effort with demonstrated results is required. Emission in the terminal area can be reduced from 60 to 80% if feasibility and practicality of a powered wheel system can be proven.

- **Control of Flight**

Although the Mach 0.98 baseline airplane was designed to U.S.-SST aft c.g. balance philosophy, it was determined that when designed for optimal performance, at the expense of inherent stability, the airplane yielded an 11.5% reduction in takeoff gross weight when compared to one designed independent of stability augmentation. Avionics studies revealed that terminal area congestion could be substantially improved by 1981 by use of improved on-board systems and operational techniques. Dual systems may be required to be compatible with advanced air traffic control implementation. Definition of the airborne-ground interface and specific requirements for the on-board system are needed. A noise reduction benefit of from 3 to 5 EPNdB below current FAR Part 36 can also be attained from work in this area.

STATE-OF-READINESS

The study showed that research and development was required in all areas before advanced technologies could be committed to a new airplane program. Based on a 5- and 6-year period, from commitment to operational status for airframe and propulsion elements, respectively, projected total lead time to operational use was established. The total lead time to operational use for major payoff technology items are therefore: supercritical airfoil technology 6 years; unidirectional composite structure 7 to 9 years; multidirectional composite structure 13 years; bonded aluminum structure 9 years; interim low noise propulsion 10 years; minimum noise propulsion 13 years; powered wheel 10 years; control configured vehicle 7 years; and improved terminal area avionics 8 years.

RECOMMENDED PROGRAM

A 10-year program involving a coordinated research and development effort by the airline, airframe and supplier industries and governmental agencies is required. Over 50 individual programs were identified that offer attractive potential. An average funding level of \$55 million per year is required, with a peak funding of \$111 million occurring in the fifth year.

EQUIPMENT AND FACILITIES

Emphasis on use of modified existing commercial transports offers the best approach to meeting the need for demonstration of the adequacy and acceptability of advanced technology development. The large financial commitment that would exist when the decision is made to proceed with an advanced transport requires that high confidence exist. This confidence must be shared by the airframe and airline industry and regulatory agencies. A building block concept can be followed, whereby existing transports can be modified to include advanced technology items as they become available. Simulated and actual operational evaluation can be then developed by all parties, during the confidence building process.

Major required facilities include: engine static test stands, structural test rigs, wind tunnel modifications and flight control simulators.

APPENDIX A

METHODOLOGY—ADVANCED TECHNOLOGY ASSESSMENT

The worth of advanced technology applications was evaluated by determining their manufacturing and operating cost impact over the life of the airplane and adding these two incremental values to obtain "total value."

A schematic diagram of the evaluation process is shown in figure 119. Changes in physical characteristics (weight, drag, SFC, etc.) of the base airplane were determined using drawings and other descriptive material defining the option. As indicated, these results became the input data for a design sensitivity analysis which yielded total value of the change, based on conventional airplane costing levels. Since the candidate technology improvement was seldom incorporated at the costing level currently used for conventional structure and systems, a manufacturing cost adjustment was usually required. An assessment of this cost adjustment on the base airplane was made by a team of representatives versed in Financial, Manufacturing and Engineering Cost Analysis, using the same definitive data which was supplied for the design sensitivity analysis.

Total value of the option was finally determined, as shown in figure 119, based on an analysis of the change in manufacturing cost required to substitute the improved technology option on the resized airplane and on the effect of that technology on the operational cost over the life of the airplane.

The impact of each advanced technology option was compared on the Model -611, which was the NASA Langley configuration concept with conventional systems and structure of the 747/DC-10 technology level. It was designed for a range of 3000 nmi (5560 km), with a design payload of 40,000 lb (18,100 kg). The Model -611 was the product of extensive design and structural analyses, providing a suitable base for evaluating the worth of advanced technology. Depth of evaluation for each option varied as a function of the expected payoff potential, data availability, the amount of coordination required and completed with non-contractor organizations, and the level of effort permitted by contract budget.

The sensitivity data mentioned above were developed to express the effect of a change in selected design parameters on a change in airplane characteristics when the airplane is cycled, i.e., resized to maintain the same payload, range, and performance. Figure 120 illustrates this effect on several economic parameters due to changing the specified design variable. The study also provided incremental changes in weight, thrust, wing size, etc., with changes in a design variable. These base data substantially aided the evaluation of potential payoff resulting from incorporation of each advanced technology option.

The change in manufacturer's empty weight (MEW) of the resized Model -611, accountable to a specified technology, is considered a significant measure of the weight payoff; however, total value has been selected as the parameter which best indicates economic worth of a given design/technology improvement. Total value is defined as the sum of the net change in manufacturing cost and the savings in cash direct operating cost over the 14-year life of the airplane, considering a 15% discount rate for money. Figures 121 and 122 depict

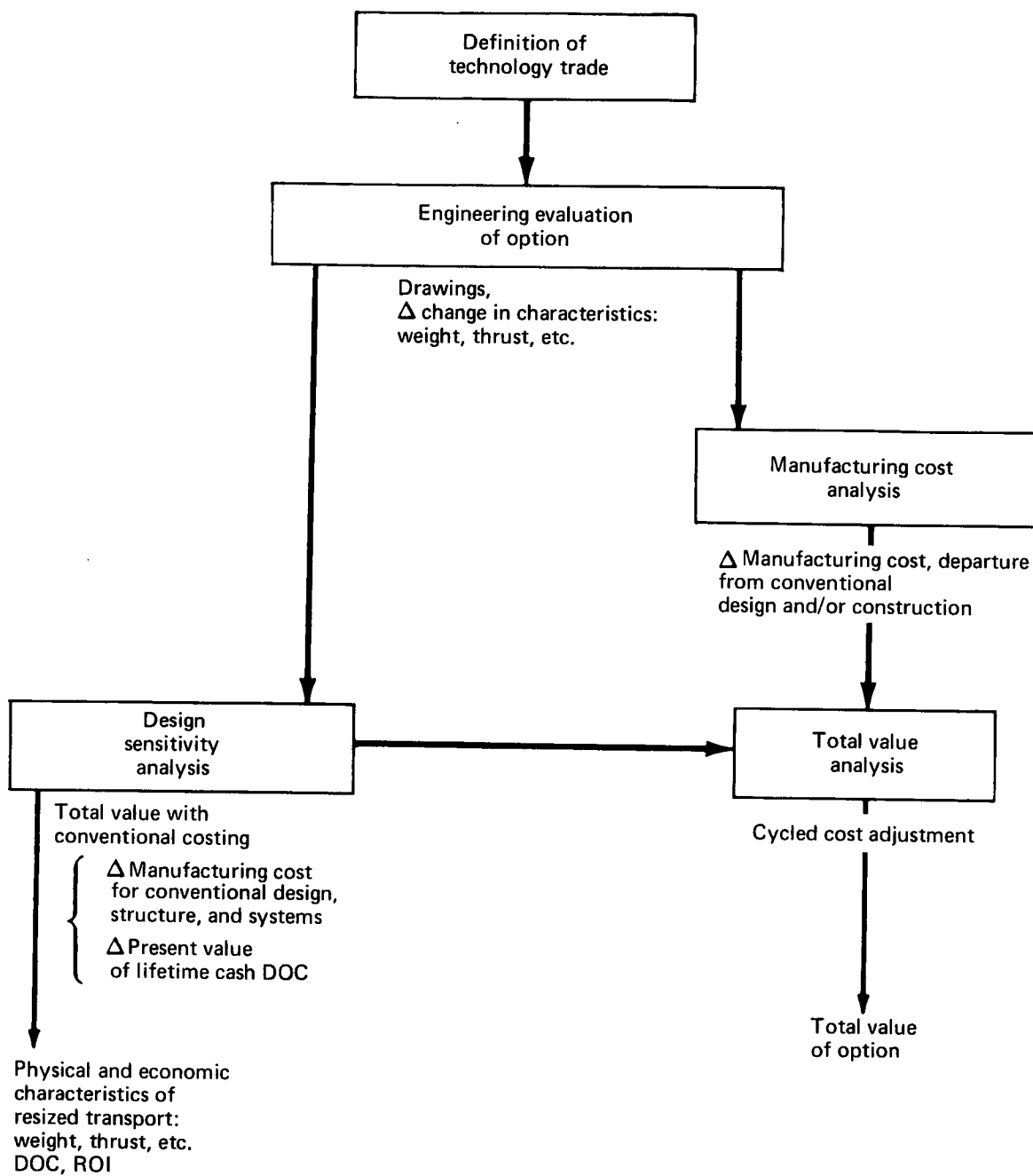


FIGURE 119.—TOTAL VALUE EVALUATION PROCEDURE

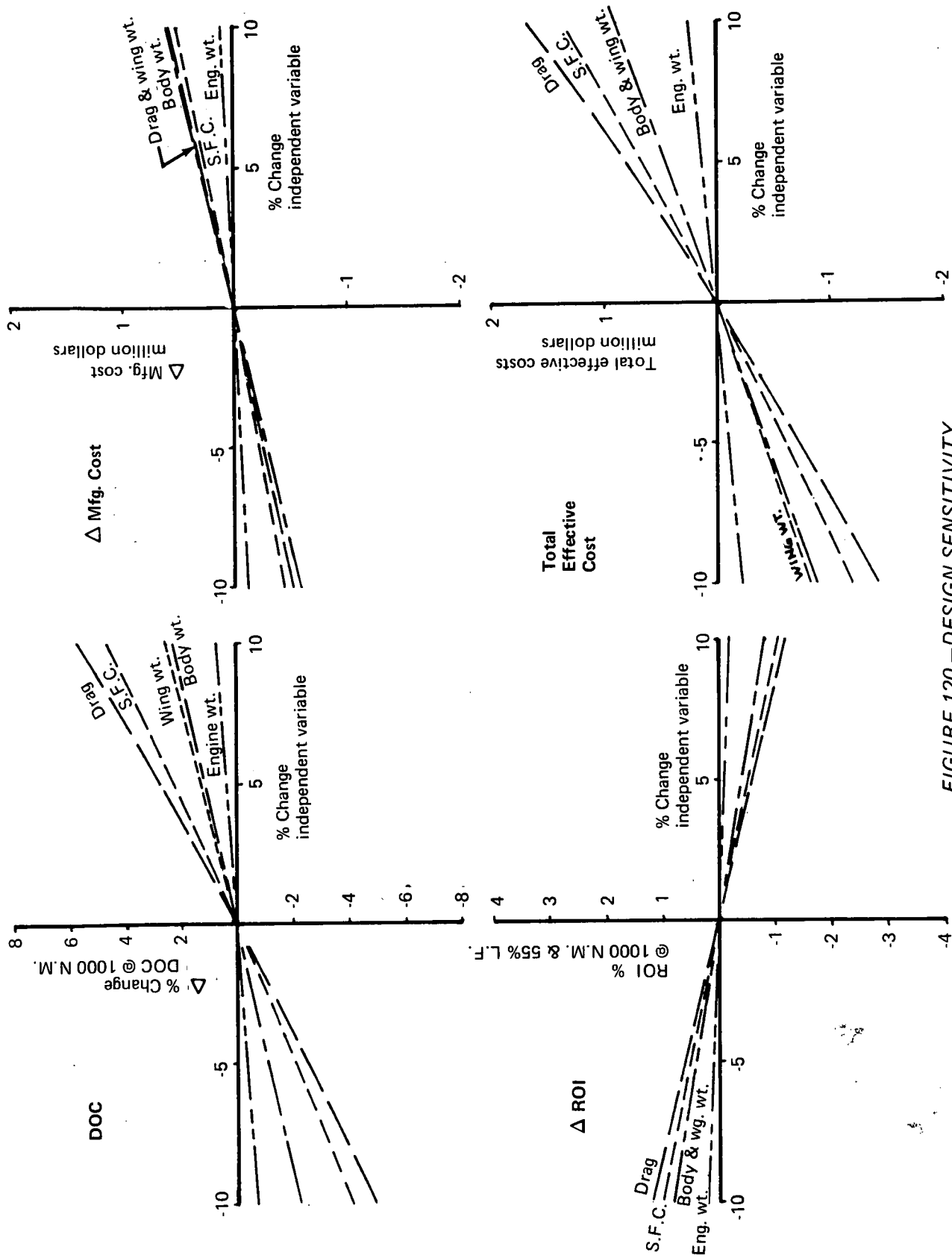


FIGURE 120.—DESIGN SENSITIVITY

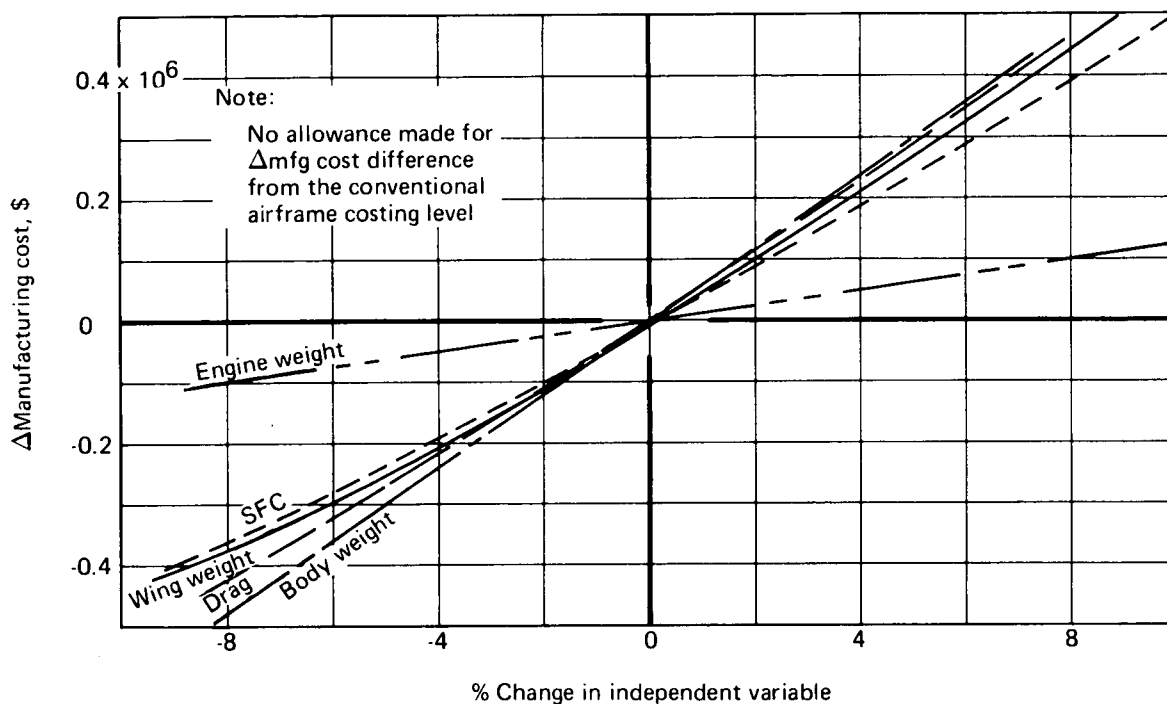


FIGURE 121.— MANUFACTURING COST SENSITIVITY,
 $M = 0.98$, 195 Seats, 2870 n mi (5320 km) Design Range (ATA)

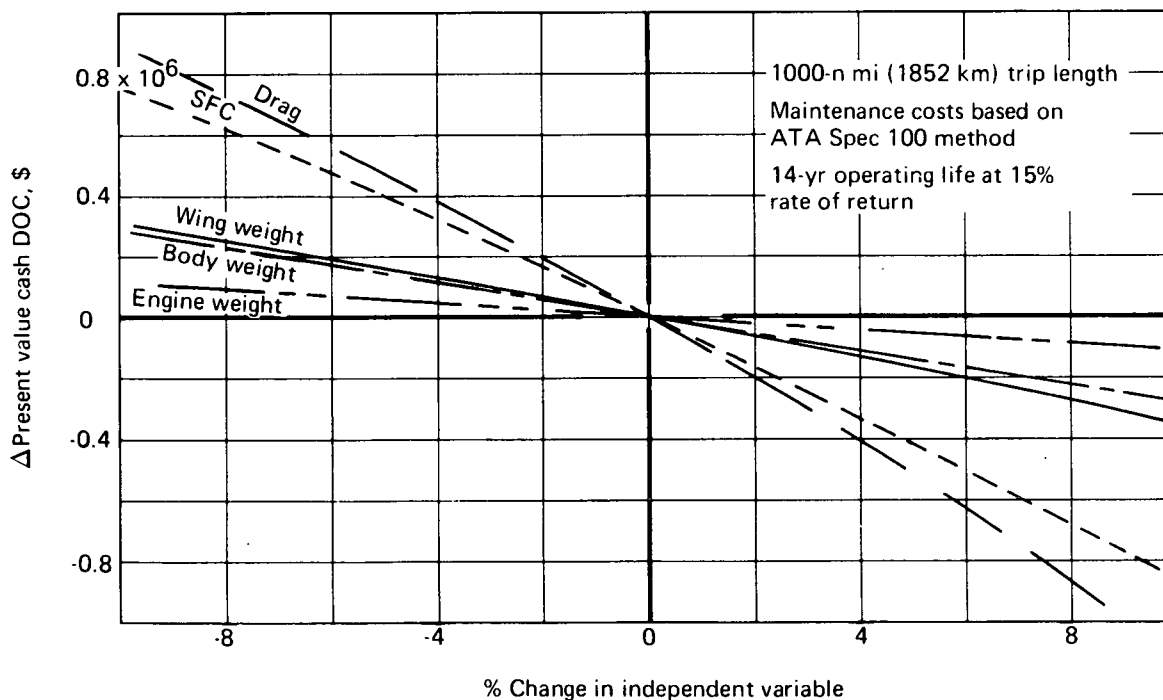


FIGURE 122.— CHANGE IN PRESENT VALUE OF LIFETIME CASH DOC,
 $M = 0.98$, 195 Seats, 2870 n mi (5320 km) Design Range (ATA)

sensitivity data for these two costs and their sum, total value, is shown in figure 123. All economic results produced by the design sensitivity study were based on current airplane costing levels.

A typical analysis procedure for evaluation of the technology trades follows:

TOTAL VALUE ANALYSIS PROCEDURE

Example Trade Study: Bonded Aluminum Structures

This trade study considered the bonding of primary structure in two areas of Model -611:

1. Bonded aluminum honeycomb body monocoque.
2. Bonded metal-metal aluminum wing box structure.

The following sequence of events for this trade study was typical of most of the advanced structures evaluations and conforms to that shown in figure 119.

1. Loads, material allowables and structural sizing were determined.
2. Structural design drawings were detailed in the affected areas.
3. The net uncycled change in empty weight due to the new structures substituted for the conventional skin/stringer construction was calculated. Results show 3240 lb (1550 kg) of weight saved on the body and 800 lb (363 kg) saved on the wing.
4. A description of the change plus the data of items 2. and 3. provided the initial basis for a cost estimate. Item 3. provided the required input for sensitivity analysis.
5. A joint Manufacturing, Engineering, and Finance review of the change was made to assess tooling and fabrication complexity relative to conventional construction. A manufacturing cost assessment determined that the integration of bonded honeycomb in specified body locations (Sections 41/43 and 46/48) had no cost increase over conventional skin and stringer construction. A manufacturing cost saving of \$57,000/airplane resulted for a redesigned -611 wing box incorporating bonded aluminum skins.
6. Summarizing the weight and cost changes to the Model -611 for bonded aluminum structure before resizing:

	Weight Saved (lb/kg)	Incremental Mfg. Cost, Adv. Tech. (Avg. for 300 Airplanes) (dollars)
Honeycomb Body	3420/1550	0
Wing Box Panels	800/363	-57,000 (saving/airplane)

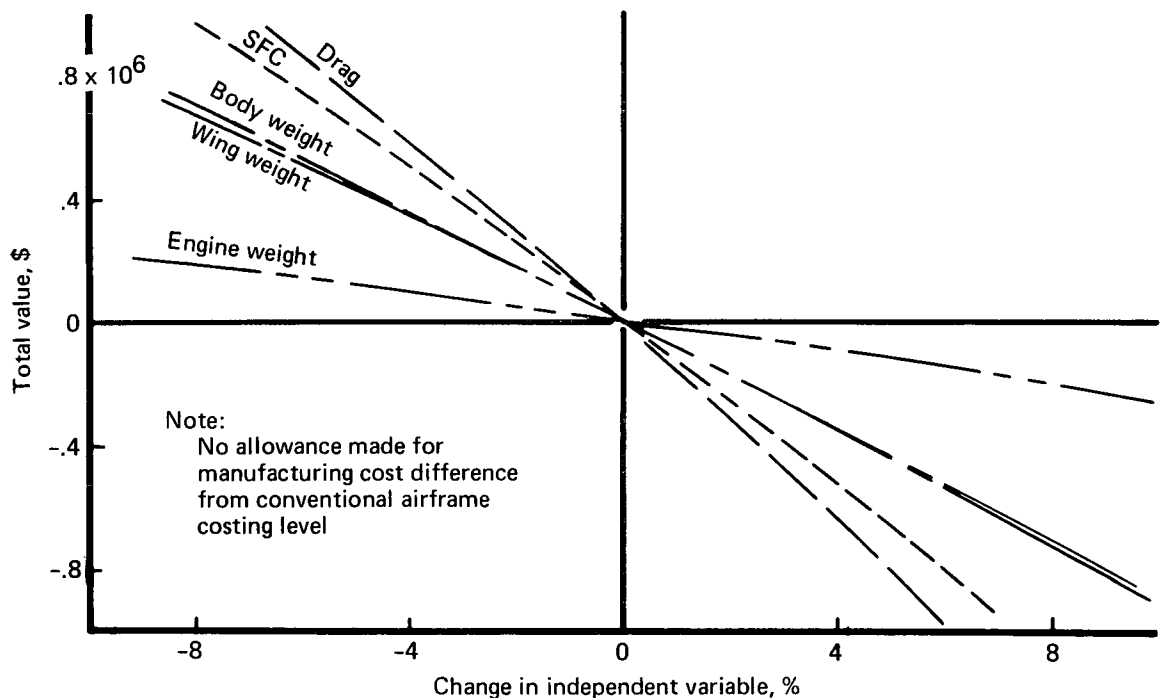


FIGURE 123.—TOTAL VALUE SENSITIVITY
(M = 0.98, 195 SEATS, 2870 NMI (5320 km) DESIGN RANGE (ATA))

TABLE 13.—TOTAL VALUE SUMMARY—BONDED ALUMINUM STRUCTURE

	Honeycomb body	Bonded skins wing box	Total bonded structure
Nominal total value (conventional cost level)	\$694 300	\$126 400	\$820 700
Incremental cost for advanced technology	0	-21 300 (saving)	-21 300 (saving)
Net total value of option	\$694 300	\$147 400	\$842 000

7. The weight savings shown above provided the required input to determine a nominal total value based on the sensitivity data; i.e., a total value based on conventional cost levels. Considering the honeycomb body, the 3420 lb (1550 kg) weight reduction (about 8% of body weight) yields a total value of about \$0.7M per airplane as determined from figure 123, and more exactly recorded as \$694,300 per airplane in table 13. A similar procedure is used for determining the nominal total value of the bonded wing box.
8. A cost adjustment to the nominal total value was made yielding a net total value of this option as shown in table 13. The \$57,000 saved on the Model -611 for incorporating the wing box (item 6.) reduces to \$21,300 on the smaller, resized airplane as indicated in figure 124.
9. Total value summed for the two improvements is \$842,000 per airplane, table 13. This potential saving for a 300 airplane quantity is about \$253 million.

A detailed total value summary for each technology option analyzed under Tasks 2 through 5 are shown on tables 14 through 17.

The tables show trade study results for a wide variety of technology trades that were conducted. Each study item for which a result is listed was conducted as a separate study. For example, the application of composites to spoilers was an individual study, separate from the analysis of composites applied to inspar wing panels. In each of these cases, the effect of the specific application upon the entire baseline airplane was determined by parametrically resizing and recosting the airplane. These detailed analyses of composite application provides insight into the potential worth of composite structures. This knowledge permitted the definition of Level I, Level II, and Level III composite applications described earlier. The Level I, II, and III definition was accomplished by application of composites on a selective basis only where the individual studies resulted in predicted benefits. In addition, Levels I, II, and III included some usage of composite structure that were not studied in separate detail. Therefore, the sum of the detailed study results listed cannot equal the weight, cost, or total value results obtained in the Level I, II, and III studies. It was not possible to develop the manufacturing cost analysis for all of the advanced technology candidate items. This was particularly true where it would have involved noncontractor efforts such as in the propulsion area. The delta cost is therefore noted as "not determined" for such items. A complete total value measurement for those items would of necessity require additional effort before firm conclusions can be drawn.

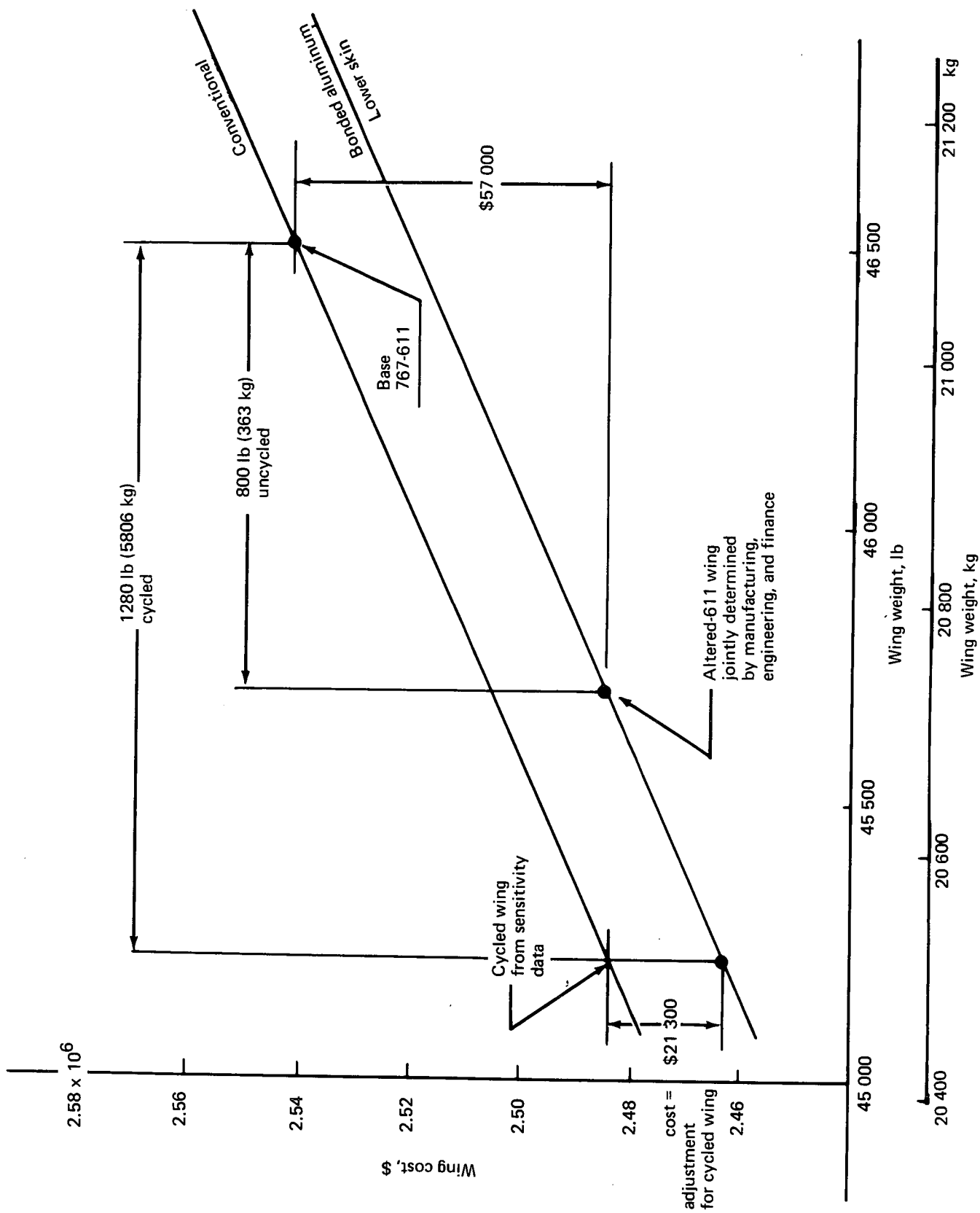


FIGURE 124.—CYCLE EFFECT ON COST AND WEIGHT—BONDED ALUMINUM WING BOX

TABLE 14.—TOTAL VALUE SUMMARY, TASK 2—AERODYNAMIC CONFIGURATION

Description	Application	Uncycled effect	Δ Cost ^a , \$	Total value, \$
Advanced airfoil	Airfoil	OEW = -5190 lb (2354 kg) ^b	0	\$+ 674 800
High critical M cowl	Cowl	OEW = -400 lb (181 kg)	Not determined	+78 000 ^c
Novel concepts	Configuration	Noise = -3 to -5 EPNdB	Not determined	+2 500 000 ^c
Subsonic/transonic area ruling	Configuration	OEW = -13 000 lb (5897 kg)	Not determined	915 000 ^c
Roughness and excrescence drag	External surfaces	Noise = -10 EPNdB	Not determined	310 000 ^c
		Drag = -5.9%		
		Drag = -2.0%		

- a. Advanced technology pricing increment at cycled airplane weight
b. Model 747 airfoil technology compared to 1980 technology at $M = 0.84$
c. Assumed conventional cost level (Δ cost = 0)

TABLE 15.—TOTAL VALUE SUMMARY, TASK 3—STRUCTURES AND MATERIALS

Description	Application	Uncycled effect	Cost ^a , \$	Total value, \$
Composite structures	Level I Level II Level III	OEW = -6600 lb (2994 kg) OEW = -9900 lb (4491 kg) OEW = -22 600 lb (10 251 kg)	\$ +929 000 +1 232 000 +2 884 000	\$ +277 000 +603 000 +1 267 000
Composite structure	Inspar wing panels Wing tank access panels Spoilers Body straps Window belts Crown stiffener and body skin Wheel well longeron Keel beam Landing gear beam and bulkhead	OEW = -3100 lb (1406 kg) OEW = -760 lb (345 kg) OEW = -170 lb (77 kg) OEW = -150 lb (68 kg) OEW = -480 lb (218 kg) OEW = -390 lb (177 kg) OEW = -20 lb (9 kg) OEW = -130 lb (59 kg) OEW = -260 lb (118 kg)	+316 800 +77 600 +13 400 +23 600 +94 000 +76 300 +4 700 +38 100 +56 300	+173 000 +42 500 +13 500 +6 900 +3 000 +1 900 -600 -12 700 -12 900
Bonded aluminum structure	Fuselage sections 41/43 Fuselage sections 46/48 Lower wing panels	OEW = -970 lb (440 kg) OEW = -2450 lb (1111 kg) OEW = -800 lb (363 kg)	0 0 -21 300	+196 900 +497 400 +147 700
Titanium structure	Wing box Wing box Wing center section Fuselage overwing Fuselage overwing Fuselage overwing Keel beam	OEW = -2120 lb (962 kg) OEW = -2110 lb (957 kg) OEW = -340 lb (154 kg) OEW = -660 lb (299 kg) OEW = -660 lb (299 kg) OEW = -590 lb (268 kg) OEW = -80 lb (36 kg)	+1 341 000 +1 050 000 +66 000 +223 000 +174 000 +129 000 +10 000	-1 009 000 -720 000 -12 000 -89 000 -40 000 -9 000 +6 000
Improved steel structure	Landing gear main Landing gear nose Flap track Wing box Body	OEW = -160 lb (73 kg) OEW = -30 lb (14 kg) OEW = -160 lb (73 kg) OEW = -2860 lb (1297 kg) OEW = -650 lb (295 kg)	+15 700 +10 300 +11 200 +1 390 000 +200 000	+18 300 -3 900 +14 100 -1 118 000 -68 000
Improved corrosion protection	Improved paint	Maintenance saving = 10% Drag = -0.4%	+470	+67 500
	High-strength clad	Maintenance saving = 90% Drag = -0.4%	-1 110	+94 200
	High-strength clad and improved heat treatment	Maintenance saving = 90% Drag = -0.4%	-630	+3 700
	Coated fasteners	—	-1 860	+1 860

a. Advanced technology pricing increment at cycled airplane weight

TABLE 16.—TOTAL VALUE SUMMARY, TASK 4—POWER SYSTEMS

Description	Application	Uncycled effect	Cost ^a , \$	Total value \$
Engine definition	Engine cycle impact	$F_{N_{TO}} = +0.50\%$ $F_{N_{CR}} = +0.50\%$ SFC = -1.50% OEW = -0.50%	Not determined	\$+421 000 ^b
Optimized Nacelle	Turbomachinery noise	Noise = 0 to -5 EPNdB	Not determined	—
	Jet noise	Noise = -10 EPNdB	—	—
	Inlet development	$F_{N_{TO}} = +0.60\%$ $F_{N_{CR}} = +0.60\%$ SFC = -.4% Drag = -0.13% OEW = -0.25% Noise = -2 EPNdB	Not determined	+195 000 ^b
	Nacelle configuration development	$F_{N_{TO}} = +0.30\%$ $F_{N_{CR}} = +0.10\%$ SFC = -.2% Drag = 0.40% OEW = -0.16%	Not determined	+165 000 ^b
	Nozzle development	$F_{N_{TO}} = +1.00\%$ $F_{N_{CR}} = +1.00\%$ SFC = -1.5% Drag = -1.00% OEW = -0.20%	Not determined	+471 000 ^b
Nacelle/airplane integration	Thrust reverser development	OEW = -0.5%	Not determined	+200 000 ^b
	Acoustic lining development	Noise = -4 to -12 EPNdB	Not determined	—
	Optimized nacelle development	Noise = -3 EPNdB	Not determined	—
Aircraft noise	Nacelle/airplane development	$F_{N_{TO}} = -0.5\%$ Drag = +0.5% OEW = -1.00%	Not determined	+320 000 ^b
	Optimized nacelle development	Noise = .3 EPNdB	—	—
Advanced auxilliary systems	Community assessment	—	Not determined	—
	Cabin interiors	Noise = -10 EPNdB	—	—
Advanced auxilliary systems	Ramp	Noise = -10 EPNdB	—	—
	Hydraulic systems	OEW = -.37%	—	+154 000 ^b
	Pneumatic, conditioning and protective systems	SFC = -1.75% Drag = -1.33% OEW = -0.38%	—	+589 000 ^b
	Electrical power and distribution	Drag = -0.80% OEW = -0.36%	—	—
	Powered wheel	65% to 80% reduced ground pollution Ramp noise = -7. to -35 EPNdB	—	—
Advanced auxilliary systems	IEG	Drag = -1.2% OEW = +0.07%	—	—
	Carbon brakes	OEW = -0.61%	+73 700	+198 300

a. Advanced technology pricing increment at the cycled airplane weight

b. Based on conventional cost level (cost = 0)

TABLE 17.—TOTAL VALUE SUMMARY, TASK 5—CONTROL OF FLIGHT

Description	Application	Uncycled effect	Δ Cost ^a , \$	Total value, \$
Active control system	Reduced structure material (flight load alleviation)	Structure = -2300 lb Systems = +595 lb	\$+131 000	\$+100 000
Control configured vehicle	Configuration concept (delete inherent stability concept)	OEW = -5550 lb Drag = -10%	+237 000	2,288,000

a. Advanced technology pricing increment at the cycled airplane weight

REFERENCES

1. Joint DOT-NASA Civil Aviation Research and Development (CARD) Policy Study Report, DOT TST-10-1, NASA CR1807, January 1971; DOT TST-10-2, NASA CR1808, February 1971 (Summary Report), DOT TST-10-3, NASA CR1809, February 1971; DOT-TST-10-4, NASA SP265, March 1971; DOT TST-10-5, NASA SP266, March 1971; Washington, D. C.
2. Overseas Business Report OBR 71-009, United States Department of Commerce, 1971.
3. Aerospace Facts and Figures, Aircraft Industries Association, 1965, 1968, and 1971.
4. Guideline for National Aviation System Planning and R&D Policy FAA-AV-71-2.
5. NASA TND-6199, "Flutter Suppression Using Active Controls Based on the Concept of Aerodynamic Energy," E. Nissim, 1971.
6. FAR Part 36, "Noise Standards: Aircraft Type Certification," December 1, 1969.